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AEDC-TR-70-251

ALTITUDE DEVELOPMENTAL TESTING OF THE J-2S ROCKET ENGINE IN ROCKET DEVELOPMENT TEST CELL J-4 (TESTS J4-1001-16 THROUGH -20)

D. E. Franklin and H. J. Counts

ARO, Inc.

November 1970

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NOTICES

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FOREWORD

The work reported herein was sponsored by the National Aeronautics and Space Administration (NASA), Marshall Space Flight Center (MSFC) (PM-EP-J), under Program Element 921E, Project 9194.

The results of the tests presented were obtained by ARO, Inc. (a subsidiary of Sverdrup & Parcel and Associates, Inc.), Contract operator of the Arnold Engineering Development Center (AEDC), Air Force Systems Command (AFSC), Arnold Air Force Station, Tennessee, under Contract F40600-71-C-0002. Program direction was provided by NASA/MSFC; technical and engineering liaison was provided by North American Rockwell Corporation, Rocketdyne Division, manufacturer of the J-2S rocket engine, and McDonnell Douglas Astronautics Company, manufacturer of the S-IVB stage. The testing reported herein was conducted between March 10 and May 19, 1970, in Rocket Development Test Cell (J-4) of the Engine Test Facility (ETF) under ARO Project No. RN1001 The manuscript was submitted for publication on August 26, 1970.

This technical report has been reviewed and is approved.

Walter C. Knapp Lt Colonel, USAF AF Representative, ETF Directorate of Test	Joseph R. Henry Colonel, USAF Director of Test

ABSTRACT

Fourteen firings of the Rocketdyne J-2S rocket engine (S/N J-115) were conducted during test periods J4-1001-16 through -20 between March 10 and May 19, 1970. The major objectives of these tests were: (1) development of a throttling capability using a variable-position tapoff valve for thrust control; (2) demonstration of satisfactory idle-mode operation (both pre- and post-main stage) over a wide range of fuel and oxidizer pump inlet pressures; (3) determine the suitability of the S-IVB propellant recirculation system to prefire condition propellants and prechill engine propellant pumps; and (4) determine steady-state engine performance during main-stage operation. All major objectives were satisfactorily accomplished.

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NOMENCLATURE

A	Area, sq in.
ASI	Augmented spark igniter
CCP	Customer connect panel
EBW	Exploding bridge wire
FM	Frequency modulation
MFV	Main fuel valve
MOV	Main oxidizer valve
O/F	Propellant mixture ratio, oxidizer to fuel, by weight
SPTS	Solid-propellant turbine starter
T/C	Thrust chamber
t-0	Time at which helium control and idle-mode solenoids are energized; engine start
VSC	Vibration safety counts, indicators of engine vibration in excess of 150 g rms in a 960- to 6000-Hz frequency range

SUBSCRIPTS

f	Force
m	Mass
t	Throat

SECTION I
INTRODUCTION

Testing of the Rocketdyne J-2S rocket engine using an S-IVB battleship stage has been in progress at AEDC since December 1968. Reported herein are the results of the fourteen firings conducted during test periods J4-1001-16 through -20 between March 10 and May 19, 1970 utilizing engine S/N J-115. The major objectives of these tests were: (1) development of a throttling capability using a variable-position tapoff valve for thrust control; (2) demonstration of satisfactory idle-mode operation (both pre- and post-main stage) over a wide range of fuel and oxidizer pump inlet pressures; (3) determine the suitability of the S-IVB propellant recirculation system to prefire condition propellants and prechill engine propellant pumps; and (4) determine steady-state engine performance during main-stage operation.

The firings were accomplished in Rocket Development Test Cell (J-4) (Figs. 1 and 2, Appendix I) of the Engine Test Facility (ETF). Pressure altitudes for the firings ranged from 93,000 to 105,000 ft (geometric pressure altitude, Z, Ref. 1) at engine start. Data collected to accomplish the test objectives are presented herein. The results of the previous test periods are presented in Ref. 2.

SECTION II
APPARATUS

2.1 TEST ARTICLE

The test article was a J-2S rocket engine (Fig. 3) designed and developed by Rocketdyne Division of North American Rockwell Corporation. The engine uses liquid oxygen and liquid hydrogen as propellants and is designed to operate either in idle mode at a nominal thrust of 5000 lbf and mixture ratio of 2.5, or at main stage at any precalibrated thrust level between 230,000 and 265,000 lbf at a mixture ratio of 5.5. The engine design is capable of transition from idle mode to main-stage operation after a minimum of 1-sec idle mode; from main stage the engine can either be shut down or make a transition back to idle-mode operation before shutdown. The engine design also has a throttling potential to any level between 100 and 20 percent of rated thrust. An S-IVB battleship stage was used to supply propellants to the engine. A schematic of the battleship stage is presented in Fig. 4.

Listings of major engine (S/N J-115) components and engine orifices for these test periods are presented in Tables I and II, respectively (Appendix II). All engine modifications and component replacements performed during this report period are presented in Tables III and IV, respectively.

2.1.1 J-2S Rocket Engine

The J-2S rocket engine (Figs. 3 and 5, Refs. 3 and 4) features the following major components:

1. Thrust Chamber—The tubular-walled, bell-shaped thrust chamber consists of an 18.6-in.-diam combustion chamber with a throat diameter of 12.192 in., a characteristic length of 35.4, and a divergent nozzle with an expansion ratio of 39.62. Thrust chamber length (from the injector flange to the nozzle exit) is 108.6 in. Cooling is accomplished by the circulation of engine fuel flow downward from the fuel manifold through 180 tubes and then upward through 360 tubes to the injector and by film cooling inside the combustion chamber.

2. Thrust Chamber Injector—The injector is a concentric-orificed (concentric fuel orifices around the oxidizer post orifices), porous-faced injector. Fuel and oxidizer injector orifice areas are 19.2 and 5.9 sq in., respectively. The porous material, forming the injector face, allows approximately 3.5 percent of main-stage fuel flow to transpiration cool the face of the injector. During idle-mode operation, oxidizer is supplied through a diffuser located in the top of the injector (Fig. 5c) which disperses the oxidizer to all portions of the injector face. During main-stage operation, the main oxidizer valve (MOV) is opened and supplies the main flow of oxidizer to the injector.

3. Augmented Spark Igniter—The augmented spark igniter unit is mounted on the thrust chamber injector and supplies the initial energy source to ignite propellants in the main combustion chamber The augmented spark igniter chamber is an integral part of the thrust chamber injector. Fuel and oxidizer are ignited in the combustion area by two spark plugs.

4. Fuel Turbopump—The fuel turbopump is a one and one-half stage, centrifugal-flow unit, powered by a direct-drive, two-stage turbine. The pump is self lubricated and nominally produces, at the 265,000-lbf-thrust rated condition, a head rise of 60,300 ft of liquid hydrogen at a flow rate of 9750 gpm for a rotor speed of 29,800 rpm.

5. Oxidizer Turbopump—The oxidizer turbopump is a single-stage, centrifugal-flow unit, powered by a direct-drive, two-stage turbine. The pump is self lubricated and nominally produces at the 265,000-lbf-thrust rated conditions, a head rise of 3250 ft of liquid oxygen at a flow rate of 3310 gpm for a rotor speed of 10,500 rpm.

6. Propellant Utilization Valve—The motor-driven propellant utilization valve is a sleeve-type valve which is mounted on the oxidizer turbopump and bypasses liquid oxygen from the discharge to the inlet side of the pump to vary engine mixture ratio.

7. Main Oxidizer Valve—The main oxidizer valve is a pneumatically actuated, two-stage, butterfly-type valve located in the oxidizer

high-pressure duct between the turbopump and the injector. The first-stage actuator positions the main oxidizer valve at the nominal 12-deg position to obtain initial main-stage-phase operation; the second-stage actuator ramps the main oxidizer valve fully open to accelerate the engine to the main-stage operating level.

8. Main Fuel Valve–The main fuel valve is a pneumatically actuated butterfly-type valve located in the fuel high-pressure duct between the turbopump and the fuel manifold.

9. Pneumatic Control Package–The pneumatic control package controls all pneumatically operated engine valves and purges.

10. Electrical Control Assembly–The electrical control assembly provides the electrical logic required for proper sequencing of engine components during operation. The logic requires a minimum of 1-sec idle-mode operation before transition to main stage.

11. Flight Instrumentation Package–The instrumentation package contains sensors required to monitor critical engine parameters. The package provides environmental control for the sensors.

12. Helium Tank–The helium tank has a volume of 4000 cu in. and provides a helium pressure supply to the engine pneumatic control system for three complete engine operational cycles.

13. Thrust Chamber Bypass Valve–The thrust chamber bypass valve is a pneumatically operated, normally open, butterfly-type valve which allows fuel to bypass the thrust chamber body during idle-mode operation.

14. Idle-Mode Valve–The idle-mode valve is a pneumatically operated, ball-type valve which supplies liquid oxygen to the idle-mode diffuser in the thrust chamber oxidizer injector during both idle-mode and main-stage operation.

15. Hot Gas Tapoff Valve–The hot gas tapoff valve is a pneumatically operated, butterfly-type valve which provides control of combustion chamber gases to drive the propellant turbopumps.

16. Solid-Propellant Turbine Starter–The solid-propellant turbine starter provides the initial driving energy (transition to main stage) for the propellant turbopumps to prime the propellant feed systems and accelerate the turbopumps to 75 percent of their main-stage operating level. A three-start capability is provided.

2.1.2 S-IVB Battleship Stage

The S-IVB battleship stage, which is mechanically configured to simulate the S-IVB flightweight vehicle, is approximately 22 ft in diameter and 49 ft long and has a maximum propellant capacity of 43,000 lbm of liquid hydrogen and ,194,000 lbm of liquid oxygen. The propellant tanks, fuel above oxidizer, are separated by a common bulkhead. Propellant prevalves, in the low-pressure ducts (external to the tanks) interfacing the stage and engine, retain propellants in the stage until being admitted into the engine to the main propellant valves, and serve as emergency engine shutoff valves. Vent and relief valve systems are provided for both propellant tanks.

Pressurization of the fuel and oxidizer tanks was accomplished by facility systems using hydrogen and helium, respectively, as the pressurizing gases. The engine-supplied gaseous hydrogen and gaseous oxygen for fuel and oxidizer tank pressurization during flight were routed to the respective facility venting systems.

2.2 TEST CELL

Rocket Development Test Cell (J-4), Fig. 2, is a vertically oriented test unit designed for static testing of liquid-propellant rocket engines and propulsion systems at pressure altitudes of 100,000 ft. The basic cell construction provides a 1.5-million-lbf-thrust capacity. The cell consists of four major components: (1) test capsule, 48 ft in diameter and 82 ft in height, situated at grade level and containing the test article; (2) spray chamber, 100 ft in diameter and 250 ft in depth, located directly beneath the test capsule to provide exhaust gas cooling and dehumidification; (3) coolant water, steam, nitrogen (gaseous and liquid), hydrogen (gaseous and liquid), liquid-oxygen, gaseous-helium, and liquid-carbon-dioxide storage and delivery systems for operation of the cell and test article; and (4) control building, containing test article controls, test cell controls, and data acquisition equipment. Exhaust machinery is connected with the spray chamber and maintains a minimum test cell pressure before and after the engine firing and exhausts the products of combustion from the engine firing. Before a firing, the facility steam ejector, in series with the exhaust machinery, provides a pressure altitude of 100,000 ft in the test capsule. A detailed description of the test cell is presented in Ref. 4.

The battleship stage and the J-2S engine were oriented vertically downward on the centerline of the diffuser/steam ejector assembly. This assembly consisted of a diffuser duct (20 ft in diameter by 150 ft in length), a centerbody steam ejector within the diffuser duct, a diffuser insert (13.5 ft in diameter by 30 ft in length) at the inlet to the diffuser duct, and a gaseous-nitrogen annular ejector above the diffuser insert. The diffuser insert was provided for dynamic pressure recovery of the engine exhaust gases and to maintain engine ambient pressure altitude (attained by the steam ejector) during the engine firing. The annular ejector was provided to suppress steam recirculation into the test capsule during steam ejector shutdown.

The test cell was also equipped with (1) a gaseous-nitrogen purge system for continuously inerting the normal air in-leakage of the cell; (2) a gaseous-nitrogen

repressurization system for raising test cell pressure after engine cutoff to a level equal to spray chamber pressure and for rapid emergency inerting of the capsule; (3) a spray chamber liquid-nitrogen supply and distribution manifold for initially inerting the spray chamber and exhaust ducting, and for increasing the molecular weight of the hydrogen-rich exhaust products; and (4) carbon dioxide distribution manifold in the diffuser for engine exhaust product molecular weight control.

2.3 INSTRUMENTATION

Instrumentation systems were provided to measure engine, stage, and facility parameters. The engine instrumentation was comprised of (1) flight instrumentation for the measurement of critical engine parameters and (2) facility instrumentation which was provided to verify the flight instrumentation and to measure additional engine parameters. The flight instrumentation was provided and calibrated by the engine manufacturer; facility instrumentation was initially calibrated and periodically recalibrated at AEDC. Appendix III contains a list of all measured engine test parameters and the locations of selected sensing points.

Pressure measurements were made using strain-gage and capacitance-type pressure transducers. Temperature measurements were made using resistance temperature transducers and thermocouples. Oxidizer and fuel turbopump shaft speeds were sensed by magnetic pickup. Fuel and oxidizier flow rates to the engine were measured by turbine-type flowmeters which are an integral part of the engine. Vibrations were measured by piezoelectric accelerometers. Primary engine and stage valves were instrumented with linear potentiometers and limit switches.

The data acquisition systems were calibrated by (1) precision electrical shunt resistance substitution for the pressure transducers and resistance temperature transducer units; (2) voltage substitution for the thermocouples; (3) frequency substitution for shaft speeds and flowmeters; and (4) frequency-voltage substitution for accelerometers and capacitance-type pressure transducers.

The types of data acquisition and recording systems used during this test period were (1) a multiple-input digital data acquisition system scanning each parameter at 50 samples per second and recording on magnetic tape; (2) single-input, continuous-recording FM systems recording on magnetic tape; (3) photographically recording galvanometer oscillographs; (4) direct-inking, null-balance potentiometer-type X-Y plotters and strip charts; and (5) optical data recorders. Applicable systems were calibrated before each test (atmospheric and altitude calibrations). Television cameras, in conjunction with video tape recorders, were used to provide visual coverage during an engine firing, as well as for replay capability for immediate examination of unexpected events.

2.4 CONTROLS

Control of the J-2S engine, battleship stage, and test cell systems during the terminal countdown was provided from the test cell control room. A facility control logic network was provided to interconnect the engine control system, major stage systems, the engine

safety cutoff system, the observer cutoff circuits, and the countdown sequencer. A schematic of the engine start control logic is presented in Fig. 6. The sequence of engine events for start and shutdown is presented in Figs. 7a and b.

SECTION III
PROCEDURE

Preoperational procedures were begun several hours before the test period. All consumable storage systems were replenished, and engine inspection, leak checks, and drying procedures were conducted. Propellant tank pressurants and engine pneumatic and purge gas samples were taken to ensure that specification requirements were met. Chemical analysis of propellants was provided by the propellant suppliers. Facility sequence, engine sequence, and engine abort checks were conducted within a 24-hr time period before an engine firing to verify the proper sequence of events. Facility and engine sequence checks consisted of verifying the timing of valves and events to be within specified limits; the abort checks consisted of electrically simulating engine malfunctions to verify the occurrence of an automatic engine cutoff signal. A final engine sequence check was conducted immediately preceding the test period.

Oxidizer injector and thrust chamber jacket purges were initiated before evacuating the test cell. After completion of instrumentation calibrations at atmospheric conditions, the solid-propellant turbine starters were installed, the test cell was evacuated to approximately 0.5 psia with the exhaust machinery, and instrumentation calibrations at altitude conditions were conducted. Immediately before loading propellants on board the vehicle, the cell and exhaust ducting atmosphere was inerted. At this same time, the cell nitrogen purge was initiated for the duration of the test period except for engine main-stage operation. The vehicle propellant tanks were then loaded and the remainder of the terminal countdown was conducted. Temperature conditioning of the various engine components was accomplished as required, using the facility-supplied engine component conditioning system. Table V presents the engine purges and thermal conditioning operations during the terminal countdown and immediately following the engine firing.

SECTION IV
RESULTS AND DISCUSSION

4.1 TEST SUMMARY

Fourteen firings of the Rocketdyne J-2S engine (S/N J-115) were conducted during five test periods (J4-1001-16 through -20) on March 10, April 1, April 15, April 30, and May 19, 1970. Pressure altitude at engine start ranged from 93,000 to 105,000 ft.

The major objectives of this test series were (1) development of deep throttling capability of the J-2S using a variable-position hot gas tapoff valve for thrust control, (2) demonstration of satisfactory idle-mode operation over a wide range of engine fuel and oxidizer pump inlet pressures and including post-main-stage idle-mode operation, (3) determine suitability of the S-IVB propellant recirculation system to prefire condition propellants and prechill engine propellant pumps, and (4) determine steady-state engine

performance during main-stage operation. A summary of significant test variables is presented in Table VI.

Test requirements and specific test results are summarized in Table VI. Start and shutdown transient operating time for selected engine valves are presented in Table VIII. Figure 8 shows engine start conditions for propellant pump inlets and helium tank.

Data presented in subsequent sections are from the digital data acquisition system, except where indicated otherwise. Propellant flow rates are based on pump discharge temperatures and pressures and on engine flowmeter calibration constants supplied by the engine manufacturer (5.5683 and 1.9219 cycles/gal for the oxidizer and fuel flowmeters, respectively).

4.2 TEST RESULTS

Primary test objectives and brief test results are presented in Appendix IV. Pertinent engine parameter performance behaviors are presented in Fig. IV-1 through IV-5 of Appendix IV. An estimated ten-percent bias existed in measured high-range chamber pressure for test periods 17, 18, and 19. An injector change was made before test period 20 in an attempt to resolve this problem. Characteristic velocity efficiency data for test period 20 indicated values consistent with pretest 16 J-2S engine main-stage values (characteristic velocity data have consistently been greater than 100 percent, indicative of an unknown chamber pressure or propellant weight flow bias). With the exception of test period 20, chamber pressure data and analysis based on chamber pressure are omitted.

4.2.1 Engine Throttling Capability

One of the design growth potentials of the J-2S rocket engine is the capability to continuously vary thrust in a main-stage configuration from 100 to 20 percent of the calibrated engine thrust level (Ref. 4). Six of the fourteen firings of this test series were conducted in support of throttle development. Engine thrust level was controlled by varying tapoff valve gate angle after the engine had attained its calibrated main-stage thrust level. The minimum steady-state chamber pressure obtained was approximately 16 percent of the main-stage level with closed propellant utilization valve, and occurred on firing 20D. Engine operation in the throttled mode was satisfactory with no operating anomalies occurring.

Figure 9 presents the tapoff valve gate angle and chamber pressure relationship as experienced during Firing 20D. From this figure it is evident the engine is quite responsive to tapoff valve gate angle changes, especially at gate angles between 28 and 31 deg. (A one-degree change in tapoff valve angle is equivalent to a 132-psia chamber pressure change.) Sensitivity decreased outside this range. Response times to gate movement were less than one second on all firings.

Figure 10 presents the total engine propellant flow rates and both injector and overall engine mixture ratios experienced during firing 20D. After the propellant utilization valve excursion, overall engine mixture ratio attained a maximum of 5.3 before throttling and decreased to approximately 4.9 at the end of the firing.

Engine operation at the lower throttle settings closely approximates the region of high thrust idle mode (200- to 350- psia chamber pressure). During previous firings, increasing resistance in the turbine system, attributed to ice formation, was experienced with the engine operating in the high thrust idle mode. High thrust idle mode was conducted with only the first stage of the main oxidizer valve open. However, throttle operation is conducted with propellant feed valves in the main-stage configuration, i.e., the main oxidizer valve fully open. This maintains the turbine tapoff gas temperature in a region that precludes ice formation or water condensation in the turbine system. Turbine temperatures experienced during firing 20D are shown in Fig. 11. The minimum steady-state temperature experienced (with closed propellant utilization valve) occurred at the liquid-oxygen turbine discharge and was approximately 500°F. Minimum temperatures realized at the null and open propellant utilization valve positions were 400 and 380°F, respectively.

Fuel pump operating characteristics during engine throttling are shown in Fig. 12. The lowest head and flow obtained were approximately 9000 ft and 1900 gpm, respectively, and occurred during firing 20D. This level is about 200 gpm below the predicted maximum head line. Fuel pump net positive suction head ranged from 700 to 900 ft during throttling, which was above the minimum operating level of 600 ft as stated by the engine manufacturer. No adverse effects on fuel pump operation occurred during the throttling tests.

4.3 IDLE-MODE OPERATION

4.3.1 Idle-Mode Operation at Pump Inlet Pressures as Constrained by the Flight Vehicle

Three low thrust idle-mode firings were conducted to evaluate engine operating characteristics over the full range of propellant temperatures and pump inlet pressures as constrained by the flight vehicle (27- to 34-psia fuel and 33- to 45-psia oxidizer). Engine combustion chamber and test cell pressures for these firings are presented in Appendix IV, Figs. IV-1a, -2e, and -4c.

The initial firing (16A) was terminated after 81.5 sec when thrust chamber throat temperatures exceeded redline limit of 200°F (Fig. 13). Fuel/oxidizer pump inlet pressures for the initial 40 sec were 33.5/30.8 psia, with a change to 33.5/45.1 psia after 40 sec (oxidizer pump inlet pressure change completed at E.S. + 57.5 sec). Thrust chamber throat temperature decreased to a minimum of -140°F at initial inlet pressures; oxidizer pump inlet pressure was then increased to 45.1 psia with the subsequent chamber temperature rise. The oxidizer idle-mode line orifice size was reduced from 0.902 to 0.725 in. to lower thrust chamber operating temperature for a subsequent firing (17C). Initial fuel/oxidizer pump inlet pressures for this firing were 34/45 psia, conditions causing the 16A cutoff. At these inlet pressures, thrust chamber skin temperature decreased from +50 to -140°F (Fig. 14). At t-0 + 34 sec, an increase in thrust chamber temperature occurred without any pump inlet pressure change. At the same time, inadvertent operation of a facility component caused a rise in cell pressure, and it is apparent heat recirculation into the test cell increased thrust chamber fuel tube resistance, causing the subsequent chamber temperature rise.

Firing 19B was successfully completed for 202.4 sec at all pump inlet pressure combinations as constrained by the flight vehicle. Fuel/oxidizer inlet pressure schedules are shown in Fig. 15. A time history of thrust chamber throat temperatures at the various pump inlet pressures are presented in Fig. 16. As noted, no excessive temperatures occurred; maximum thrust chamber skin temperature of 0°F occurred at inlet pressures of 27/45 psia (fuel/oxidizer).

Engine performance is not presented since fuel flow cannot be accurately defined (pressure temperature at the engine fuel flowmeter indicated two-phase flow throughout idle mode). Subcooled fuel at the flowmeter was noted after approximately 55 sec of firing 17C, but performance is not presented because of excessive cell pressure and temperature. Oxidizer flow rates were 11.2 and 7.6 lbm/sec, respectively, with 0.902- and 0.725-in. oxidizer idle-mode line orifices and 45-psia oxidizer pump inlet pressure (at similar fuel pump inlet pressures, chamber pressure was 29.4 and 24.7 for the two orifice sizes).

4.3.2 Idle-Mode Operation in Support of Interim 21 Program

One idle-mode firing (20E) was conducted in support of interim 21, a proposed program to utilize the Saturn V, S-II Stage as a space station. Fuel/oxidizer pump inlet pressures were 25/25 psia for the initial 75 sec, and 25/20 psia for the remaining 25 sec. Thrust chamber temperature was about +60°F at t-0 and decreased throughout the firing to -320°F at shutdown (Fig. 17). Combustion chamber pressure averaged about 18 psia (Appendix IV, Fig. IV-4c) over the last 60 sec. Performance is not presented because of inability to define fuel flow (pressure-temperature data indicated two-phase conditions at the fuel flowmeter).

Leakage past the hot gas tapoff valve was sufficient to spin the fuel pump during all idle-mode operation. Fuel pump speed varied from 550 to 1300 rpm. No rotation of the oxidizer pump was observed.

4.3.3 Post-Main-Stage Idle Mode

An 11-sec post-main-stage idle mode was successfully conducted during firing 20A. Engine operation was satisfactory and no anomalies were noted. Chamber pressure decreased to a minimum of 24 psia about 12 sec after main-stage cutoff (Fig. 18). Thrust chamber throat temperature increased from -300 to -75°F between main-stage cutoff and engine cutoff.

4.4 MAIN-STAGE OPERATION

One long-duration main-stage firing (20A, 29.5 sec in duration) was conducted during this series. The firing was accomplished with a propellant utilization valve excursion from null to closed position.

Engine operation was satisfactory, but performance data (i.e., characteristic velocity and specific impulse) are omitted since calculated values are in excess of 100 percent theoretical (this is consistent with pretest 16 J-2S engine main-stage performance values).

It is probable that a chamber pressure bias existed, but there is a possibility that total propellant weight flow was low. Indicated chamber pressure just before main-stage cutoff was 1200 psia; total propellant weight flow was 569 lbm/sec at an oxidizer/fuel mixture ratio of 5.4.

Vibrations, predominantly in the frequency range of 4700 to 4800 Hz, were recorded with accelerometers mounted on the oxidizer dome and oxidizer pump during the latter part of firing 20A. Other predominant frequencies, noted from an oxidizer pump radial accelerometer, were 2200 and 3100 Hz; 4700-4800 Hz were also indicated. Vibration data from two oxidizer dome and one oxidizer pump radial accelerometer were evaluated using a power spectral density analysis (Appendix V), and are shown in Fig. 19. Summarized below are predominant frequencies and vibration power level:

	Accelerometer	Frequency, Hz.	Peak Acceleration, g rms
UTCD-1	Oxidizer Injector Dome 1	4750	22.1
UTCD-2	Oxidizer Injector Dome 2	2000	3.0
UTCD-2	Oxidizer Injector Dome 2	4750	17.7
UTCD-2	Oxidizer Injector Dome 2	6000	2.9
UOPR	Oxidizer Pump Radial	2100	8.5
UOPR	Oxidizer Pump Radial	3100	20.6
UOPR	Oxidizer Pump Radial	4750	19.1

4.5 ENGINE TRANSIENT OPERATION

Engine operation during transition to main stage can be seen in Figs. IV-2 through -5 in Appendix IV. With exception of premature termination of two firings, transition was satisfactory. These two firings were terminated early because of an excessive delay in augmented spark igniter ignition detect delay signal (facility logic requires ignition signal at main-stage start signal). Ignition actually occurred in both cases, and no detrimental effects would have been experienced had the automatic kill been eliminated. The ignition delay was apparently caused by a reduced oxidizer/fuel mixture ratio in the augmented spark igniter chamber (effects of bleed valve installation) during start transient, lowering combustion temperature (augmented spark igniter probes are heat sensitive elements). To circumvent this problem, pre-main-stage idle mode was extended and chamber pressure used to indicate ignition.

The S-IVB battleship stage propellant recirculation system was utilized prefire 20A, 20B, 20C, and 20D to temperature condition propellants and engine pumps. Engine bleed valves were installed pretest 19, but recirculation pump problems prevented use of this system.

Propellant and engine pump hardware temperature data from test 20 are comparable with those from tests in which prevalves were opened prefire continuously for 60 min minimum. Normal sequence for the recirculation system was (1) at t-60 min open prevalves, (2) at t-15 min close prevalves, open recirculation valves and start recirculation pumps, and (3) at t-5 sec open prevalves, close recirculation valves, and stop recirculation pumps.

4.6 TEST ANOMALIES SUMMARY

4.6.1 Chamber Pressure Measurement

An estimated 10-percent bias existed in chamber pressure measurement on test periods 16 through 19. An analysis by Rocketdyne indicates the problem was caused by a flow path from the fuel injector manifold to the chamber pressure measurement tap. An injector change was made before test period 20 to resolve the problem; significant improvement was noted. However, a small bias was still present. With the exception of test 20, all chamber pressure data are omitted from this report.

4.6.2 Electrical Control Assembly Problems

The electrical control assembly package was replaced three times during the test series because of electrical problems. Initial replacement was before test 16 when an engine sequence check indicated absence of an engine cutoff lockin signal at shutdown. A resistance check of the cutoff lockin circuitry indicated an electrical short in the electrical control assembly. An engine sequence check with the new electrical control assembly indicated the augmented spark igniter No. 2 spark exciter to be defective. However, the package was used for test 16 and replaced before test 17.

The electrical control assembly package was replaced again pretest 19 because of inability to reset the cutoff lockin signal.

Both cutoff lockin problems were caused by inadequate facility electrical resistance in the facility electrical control assembly circuitry. A facility modification was incorporated before test 19 to increase protective resistance from 200 to 1300 ohms (specified minimum resistance 300 ohms).

4.6.3 Tapoff Valve Control Problems

Problems were experienced with the operation of the variable position hot gas control valve during test period 17. The valve did not respond normally during firing 17B and could not be operated at all before 17C. From a posttest evaluation, it was concluded that hydraulic fluid used for tapoff valve stop control had become chilled, affecting system response. Inability to operate the valve before 17C was attributed to chilldown of hydraulic fluid below pour point (-30°F). This problem was resolved for subsequent tests by shielding and insulating the hydraulic supply line from cold gases used to condition engine components.

4.6.4 Augmented Spark Igniter Ignition Detect Delay

Augmented spark igniter ignition detect was delayed during test periods 19 and 20. Two firings were prematurely automatically terminated when the augmented spark igniter ignition detect signal was not present at main-stage start signal as required by facility logic. Ignition actually occurred and no detrimental effects would have resulted had the automatic kill been eliminated. Excessive ignition detect delay was attributed to engine

bleed valve installation which was believed to have reduced the augmented spark igniter chamber oxidizer/fuel mixture ratio during start transient (augmented spark igniter probes are heat sensitive elements). When necessary, the problem was resolved by eliminating the automatic kill requirement, extending pre-main-stage idle-mode duration, and using chamber pressure as ignition indicator (minimum of 10 psia required after two sec).

Firing 20C was terminated early when a propellant utilization valve excursion was made prematurely (manual kill active if propellant utilization valve position is not in null position ±2 deg, active from main-stage start plus 4.5 sec). This problem resulted when idle-mode duration was extended after the augmented spark igniter ignition detect delay occurred. Target idle-mode duration was 5 sec, but because of poor timer resolution, idle-mode duration was 9.2 sec.

4.6.5 Oxidizer Idle-Mode Valve

The oxidizer idle-mode valve was replaced before test period 18. This was required because of out-of-specification closing time.

SECTION V
SUMMARY OF RESULTS

The results of the fourteen firings of the J-2S engine conducted during test periods J4-1001-16 through -20 are summarized as follows:

1. The throttling capability of the J-2S rocket engine was successfully demonstrated using a variable position tapoff valve for control. The minimum level obtained was approximately 16 percent of the rated main-stage operating level.

2. The J-2S engine was successfully operated in low thrust idle-mode operation over the full range of propellant temperatures and pump inlet pressures as presently constrained by the flight vehicle. One post-main-stage idle-mode firing was also successfully conducted.

3. A 100-sec low thrust idle-mode firing was successfully conducted at reduced pump inlet pressures in support of the Interim 21 Program (proposed program to utilize the Saturn V, S-II Stage as a space station).

4. Engine operation during a 30-sec main-stage firing was satisfactory. Vibrations with predominant frequencies of 3100 and 4750 Hz were observed during the latter stages of the firing.

5. The S-IVB battleship stage recirculation system was successfully used to temperature condition propellant and pump temperature during test period 20. Augmented spark igniter ignition was delayed during engine start transient with the bleed valves installed.

REFERENCES

1. Dubin, M., Sissenwine N., and Wexler, H. U. S. Standard Atmosphere, 1962. U. S. Government Printing Office, December 1962.

2. Pillow, C. E. "Altitude Developmental Testing of the J-2S Rocket Engine in Rocket Development Test Cell (J-4) (Tests J4-1001-06, -07, -11 and -15)." AEDC-TR-70-204 (AD874400L), September 1970.

3. "J-2S Interface Criteria." Rocketdyne Document J-7211, October 16, 1967.

4. "Engine Model Specification Oxygen/Hydrogen Liquid-Propellant Rocket Engine Rocketdyne Model J-2S." Rocketdyne Document R-2158 dS, August 21, 1968.

APPENDIXES

I. ILLUSTRATIONS
II. TABLES
III. INSTRUMENTATION
IV. FIRING SUMMARY
V. POWER SPECTRAL DENSITY WAVE ANALYSIS

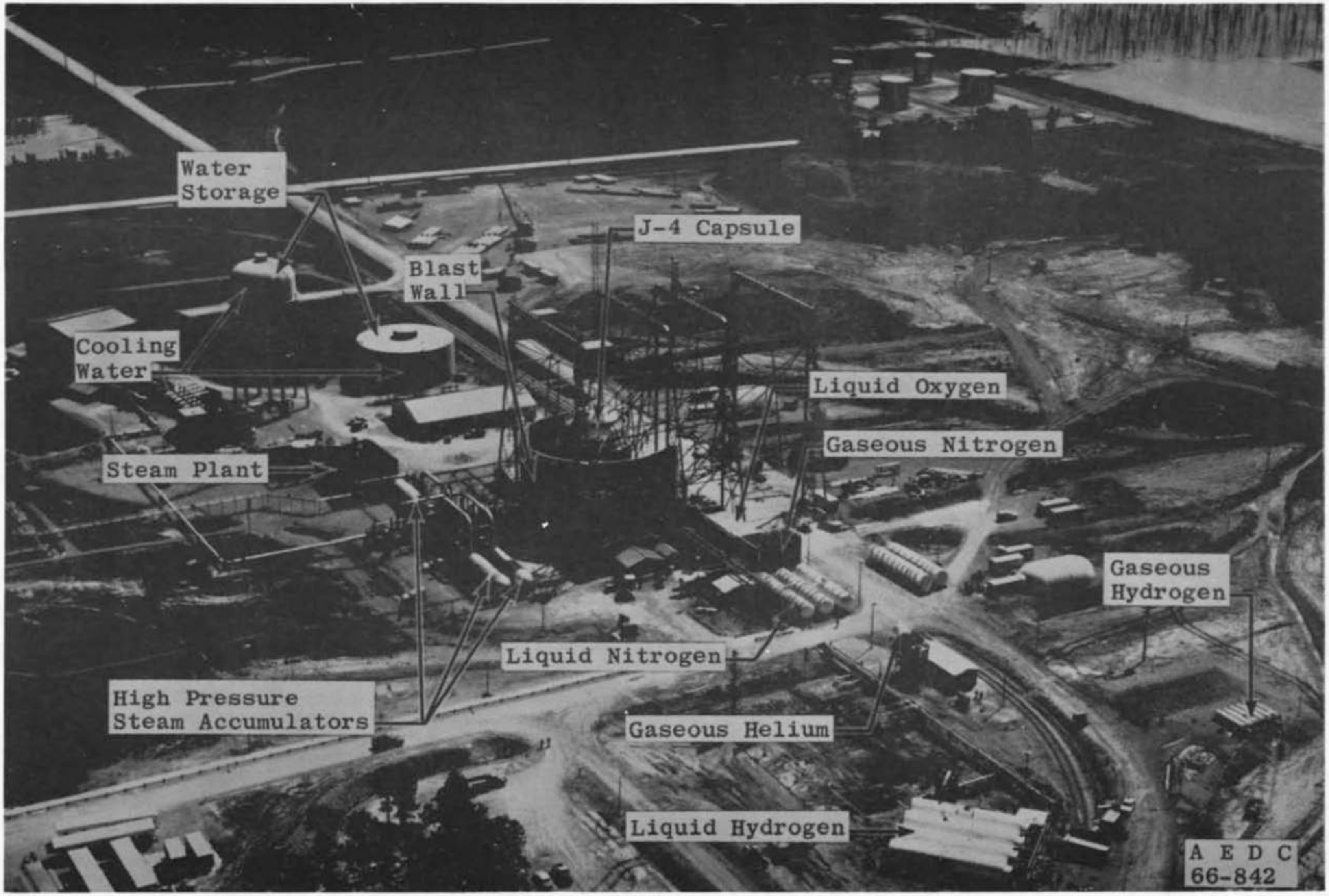


Fig. 1 Test Cell J-4 Complex

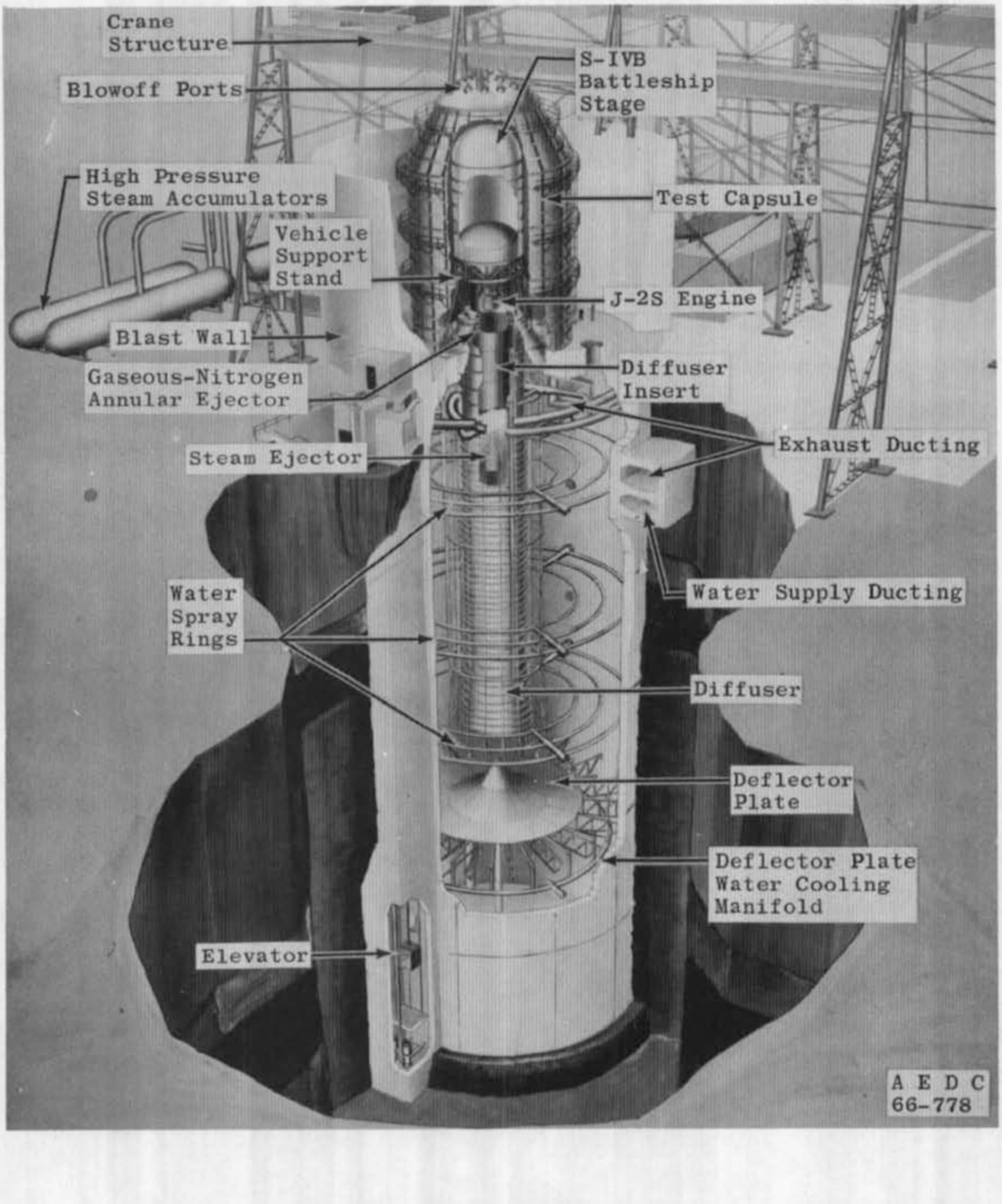


Fig. 2 Test Cell J-4, Artist's Conception

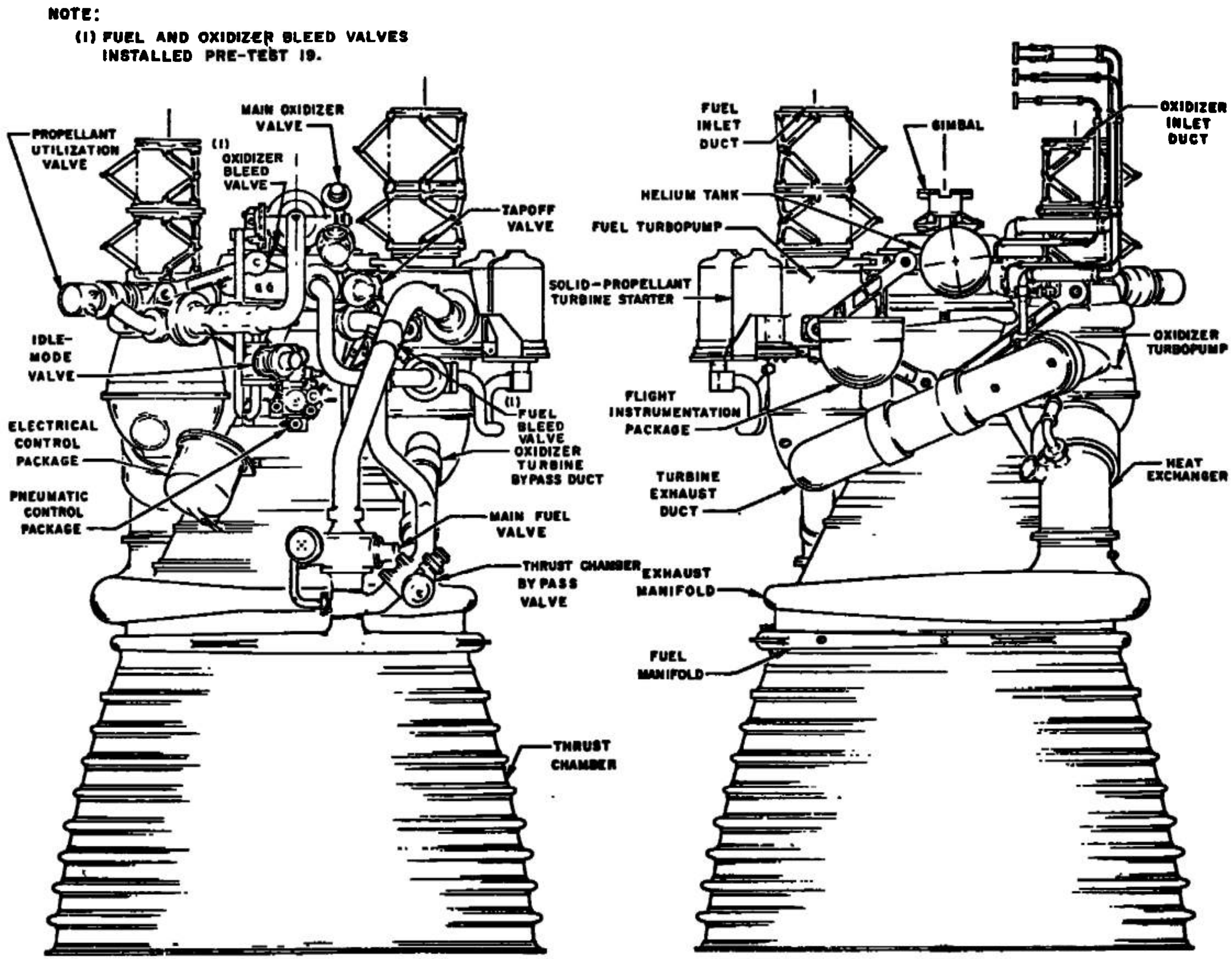


Fig. 3 J-2S Engine General Arrangement

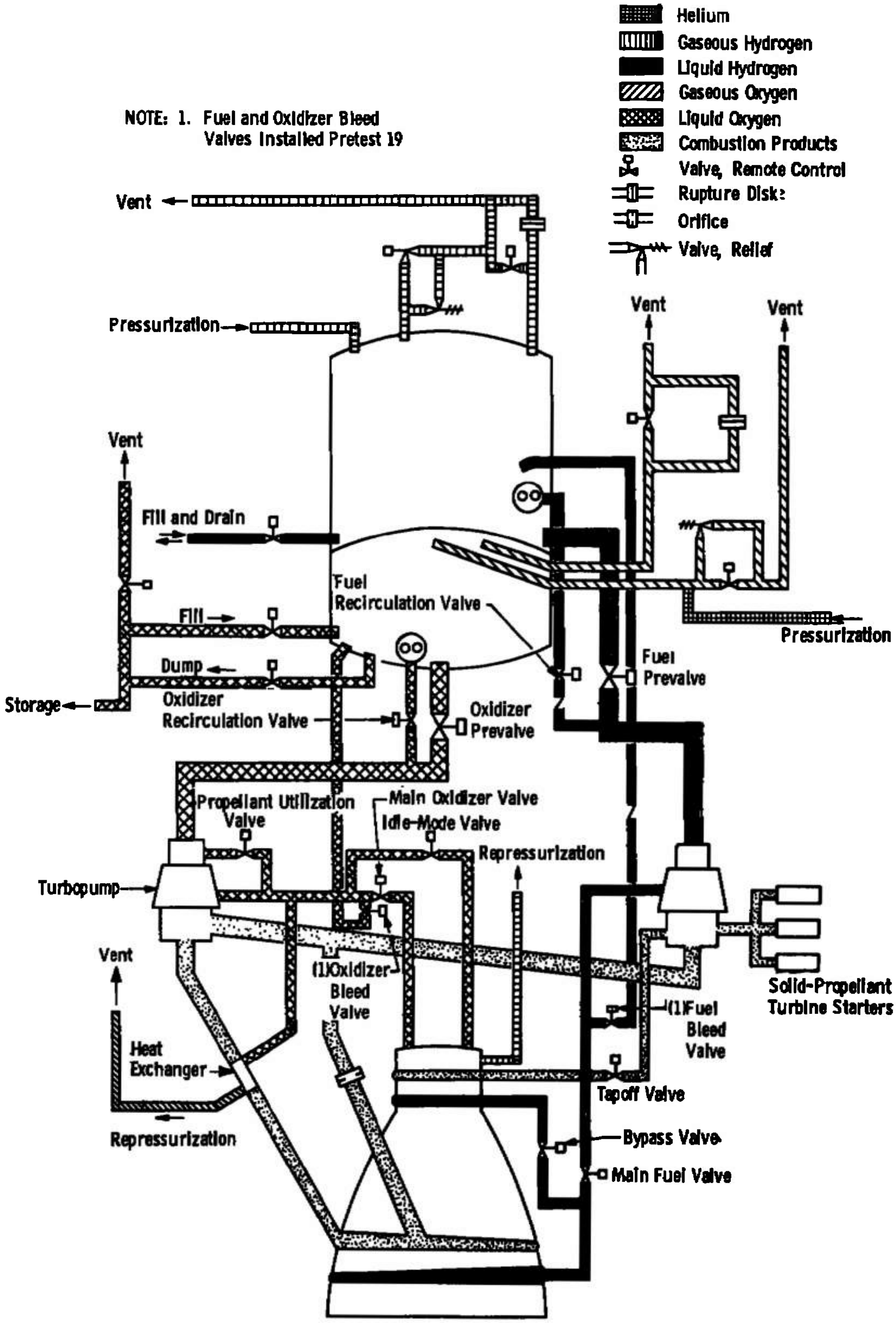
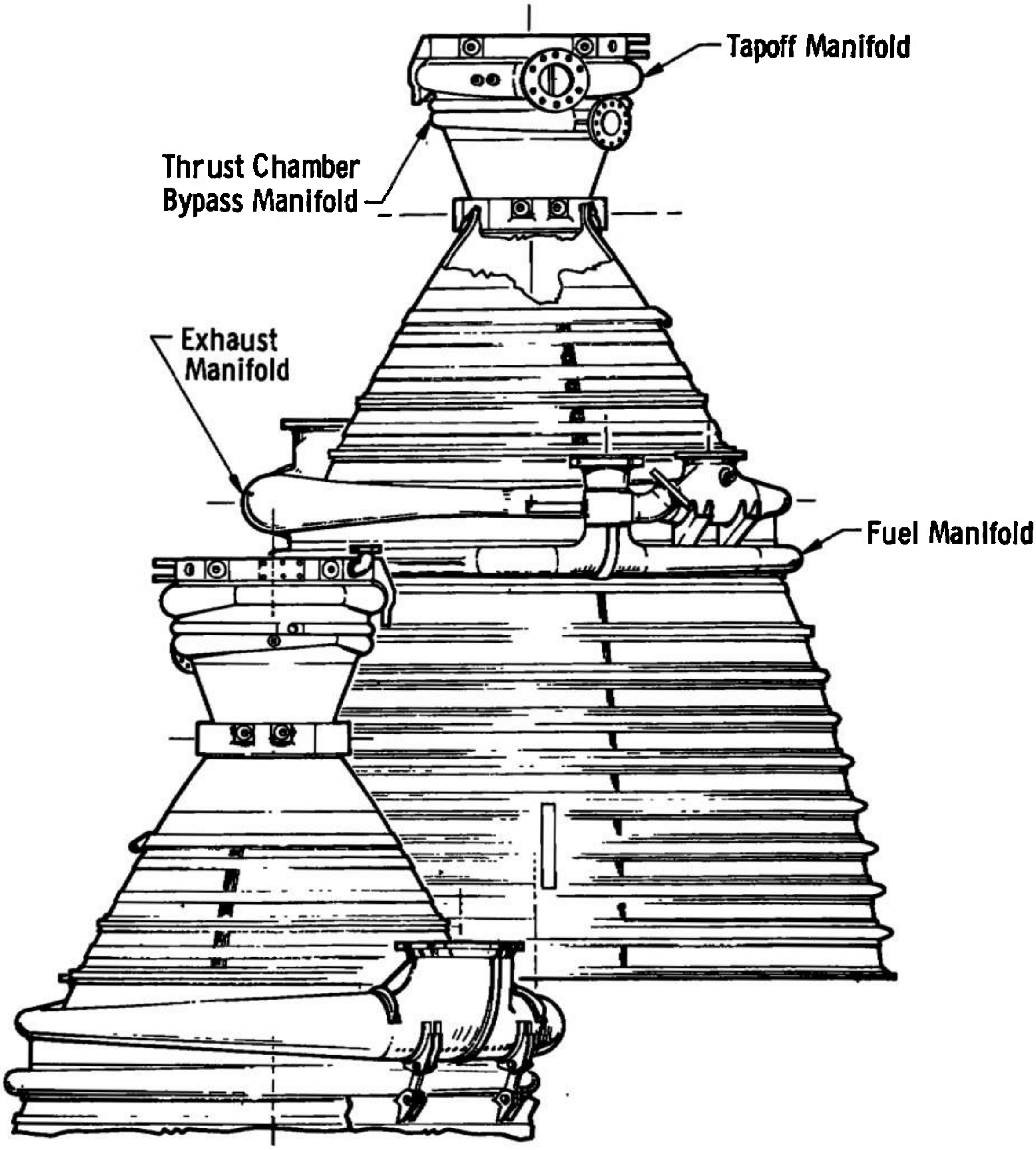
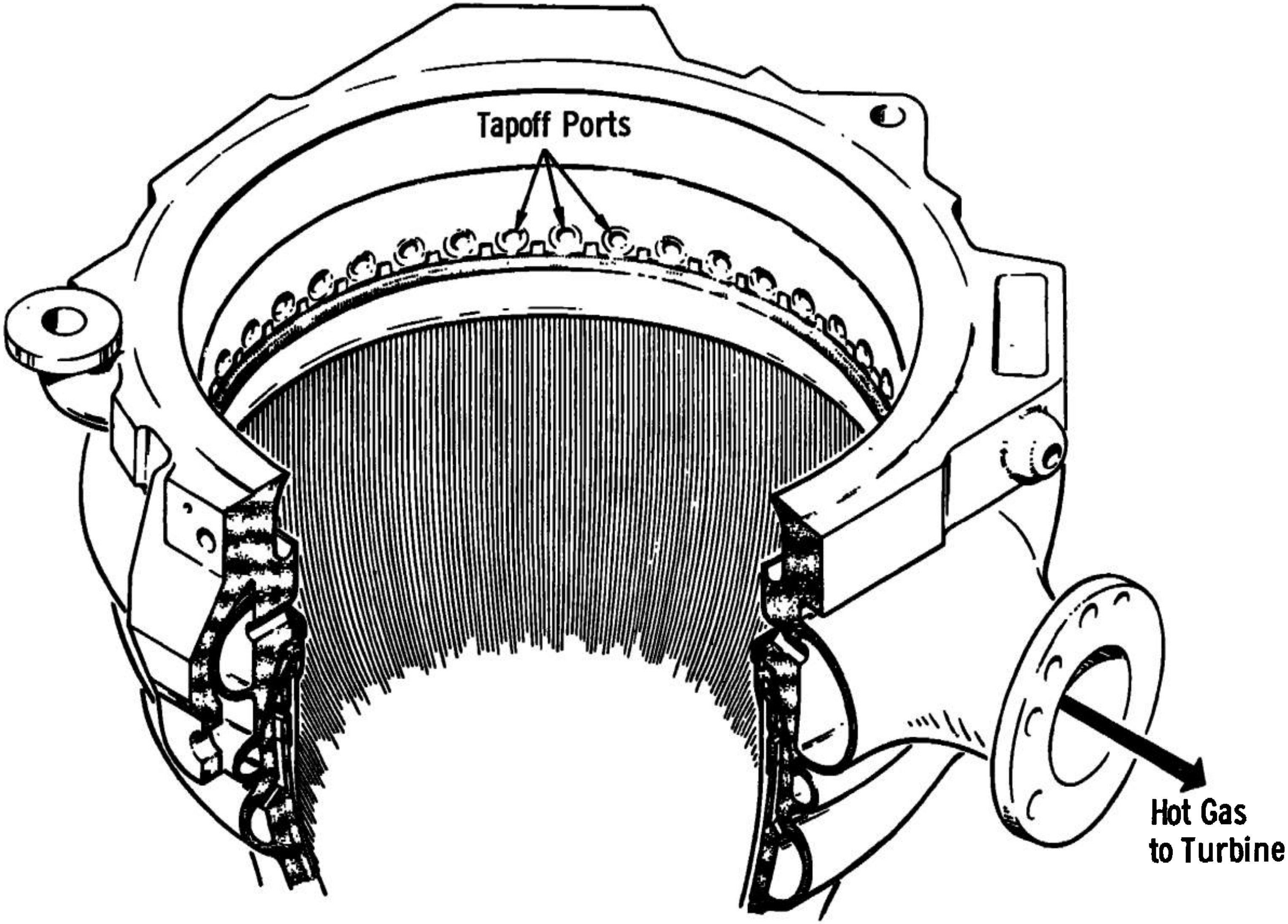


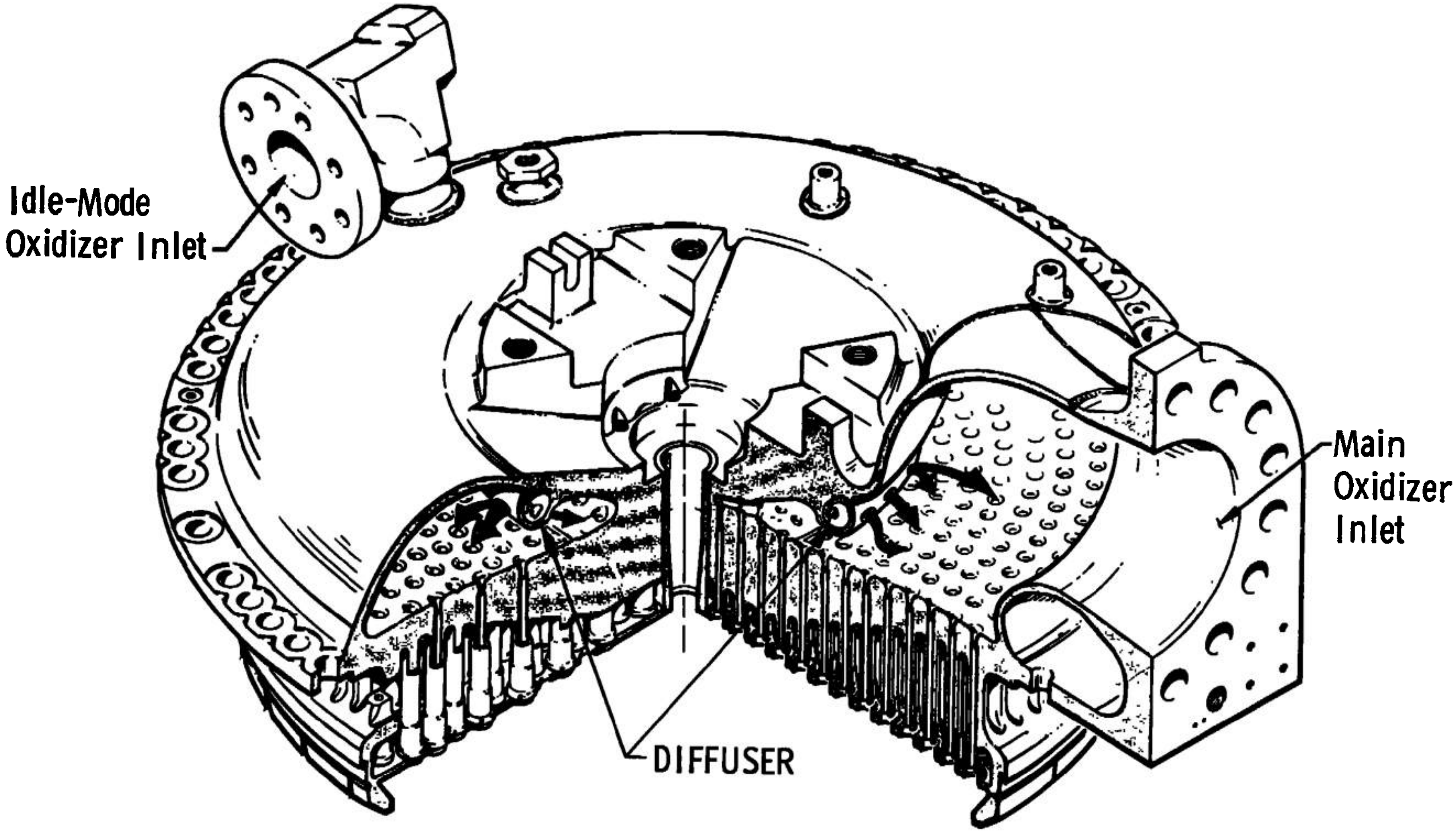
Fig. 4 S-IVB Battleship Stage/J-2S Engine Schematic



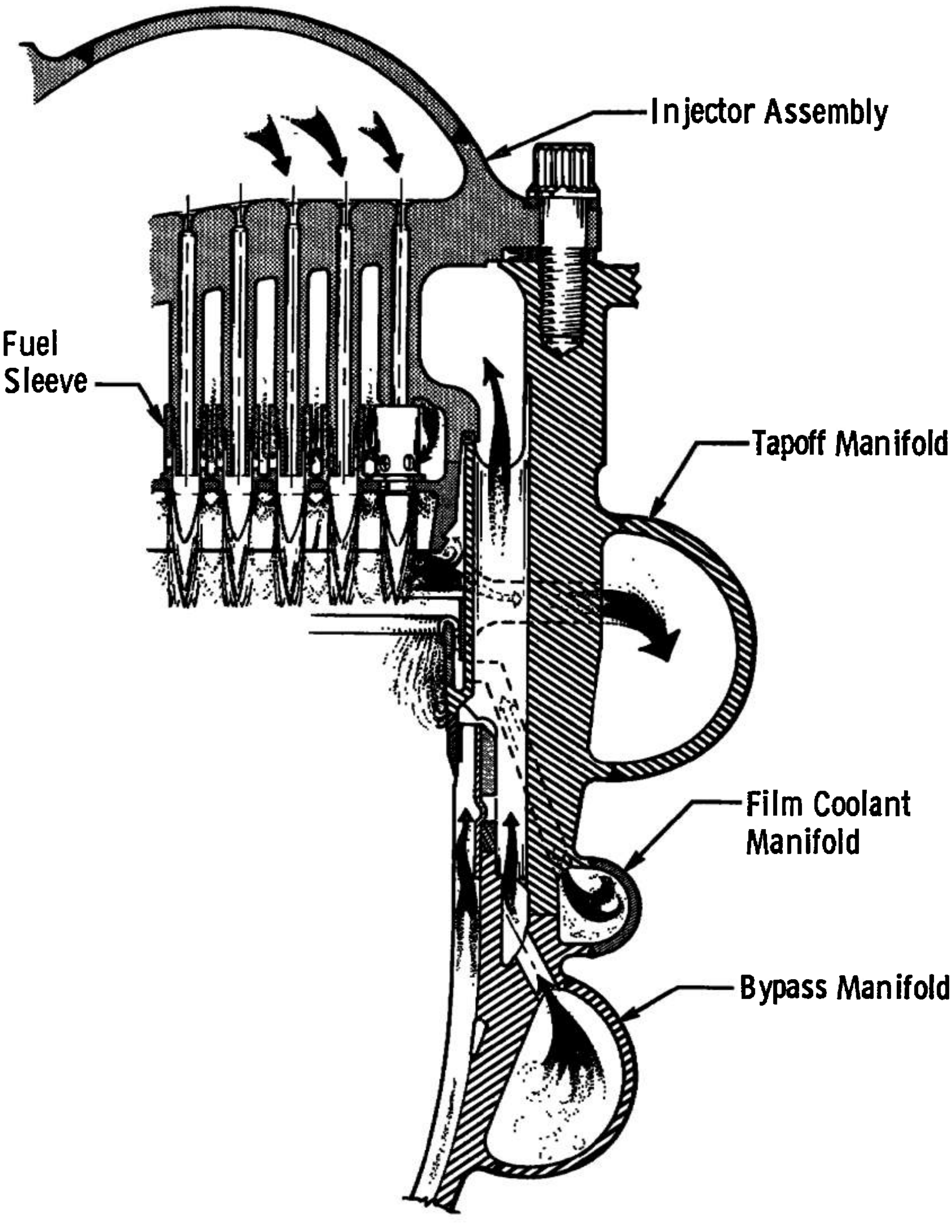
a. Thrust Chamber
Fig. 5 Engine Details



b. Combustion Chamber
Fig. 5 Continued



c. Injector
Fig. 5 Continued



d. Injector to Chamber
Fig. 5 Concluded

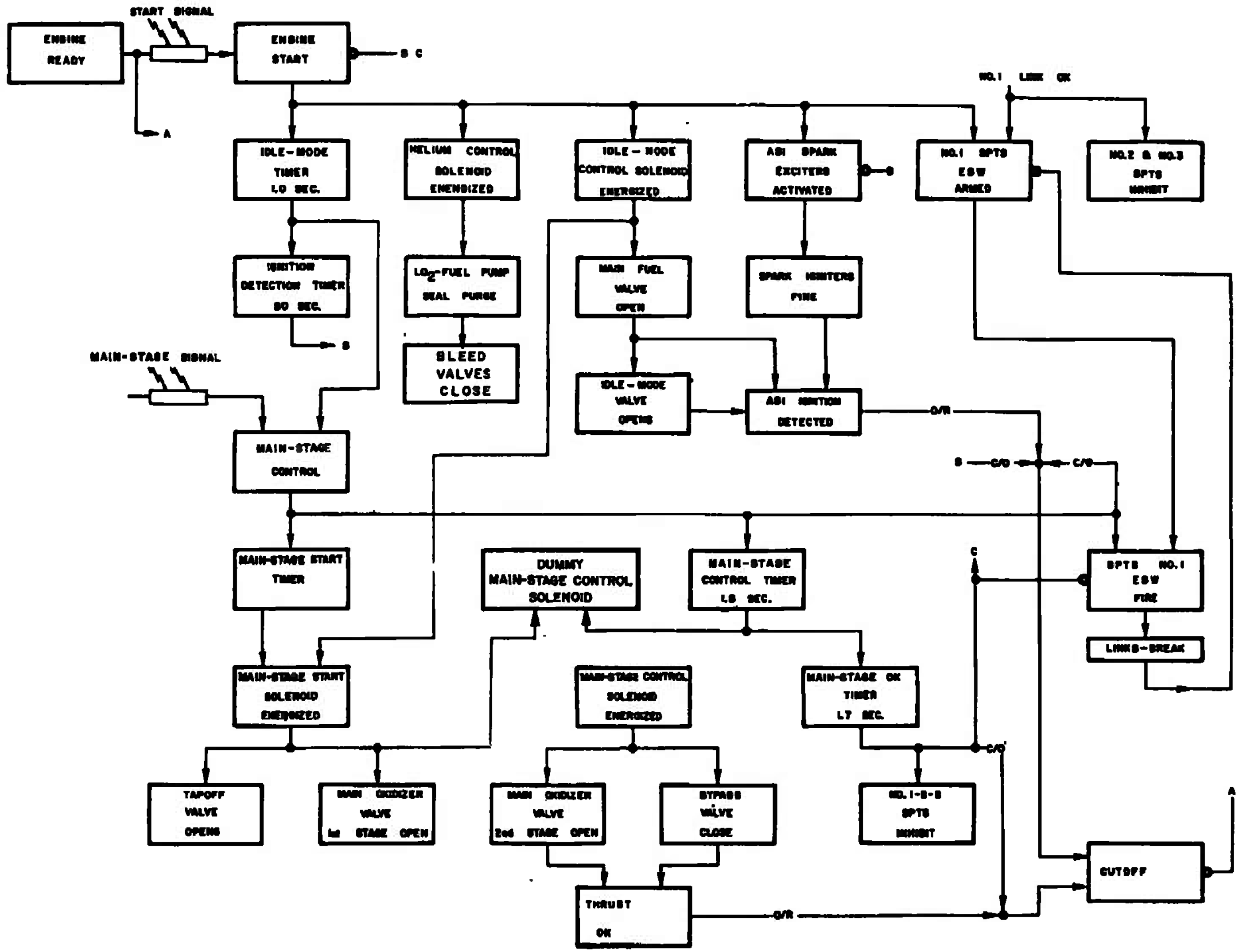
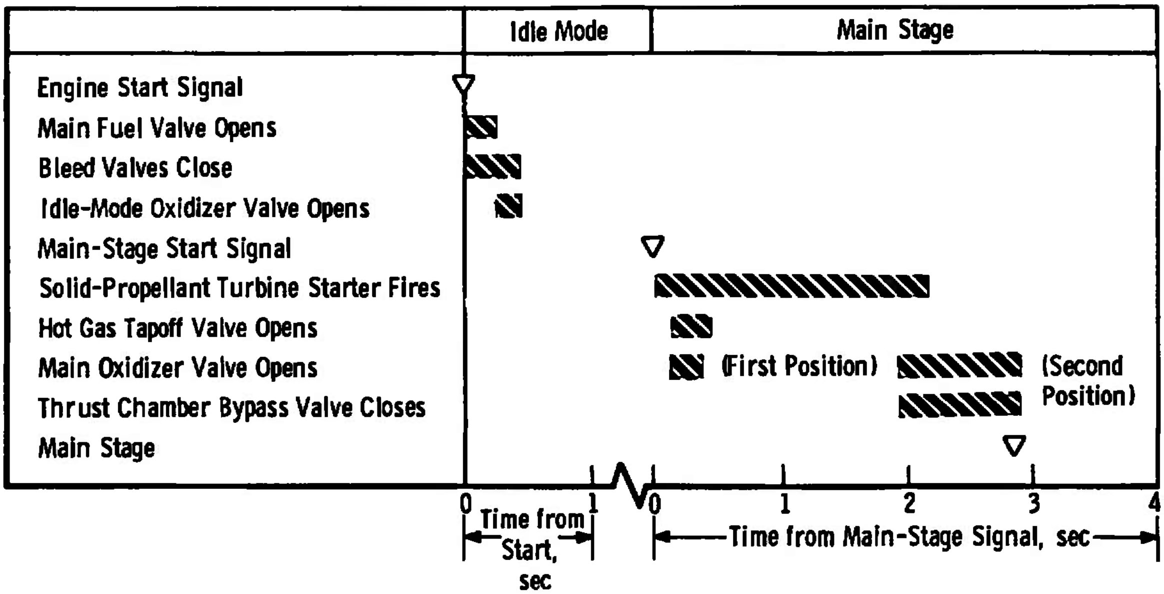
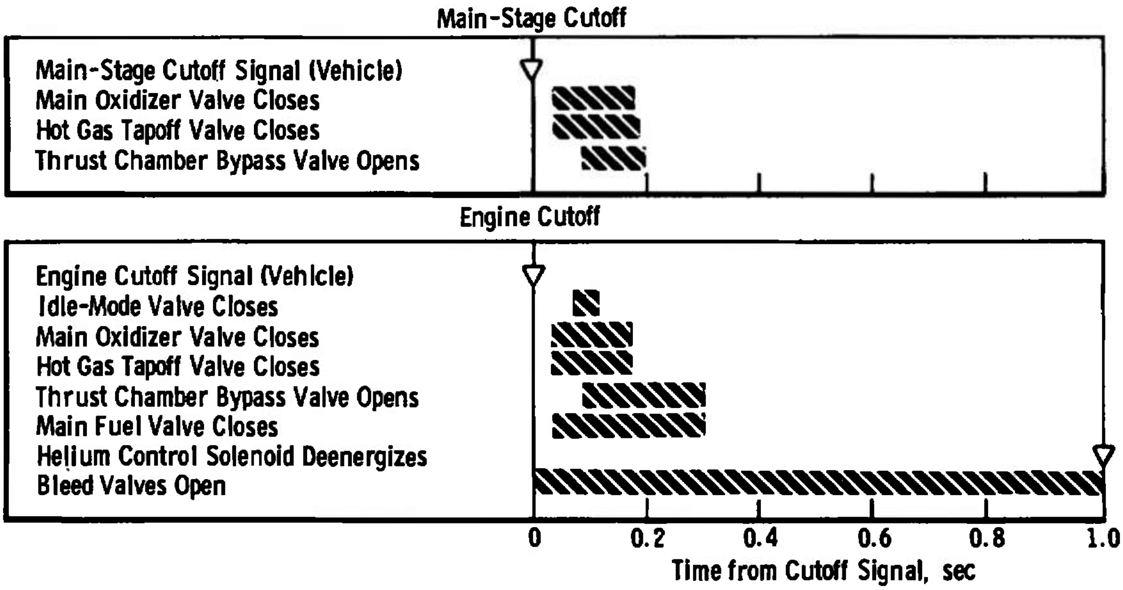


Fig. 6 Engine Start Logic Schematic

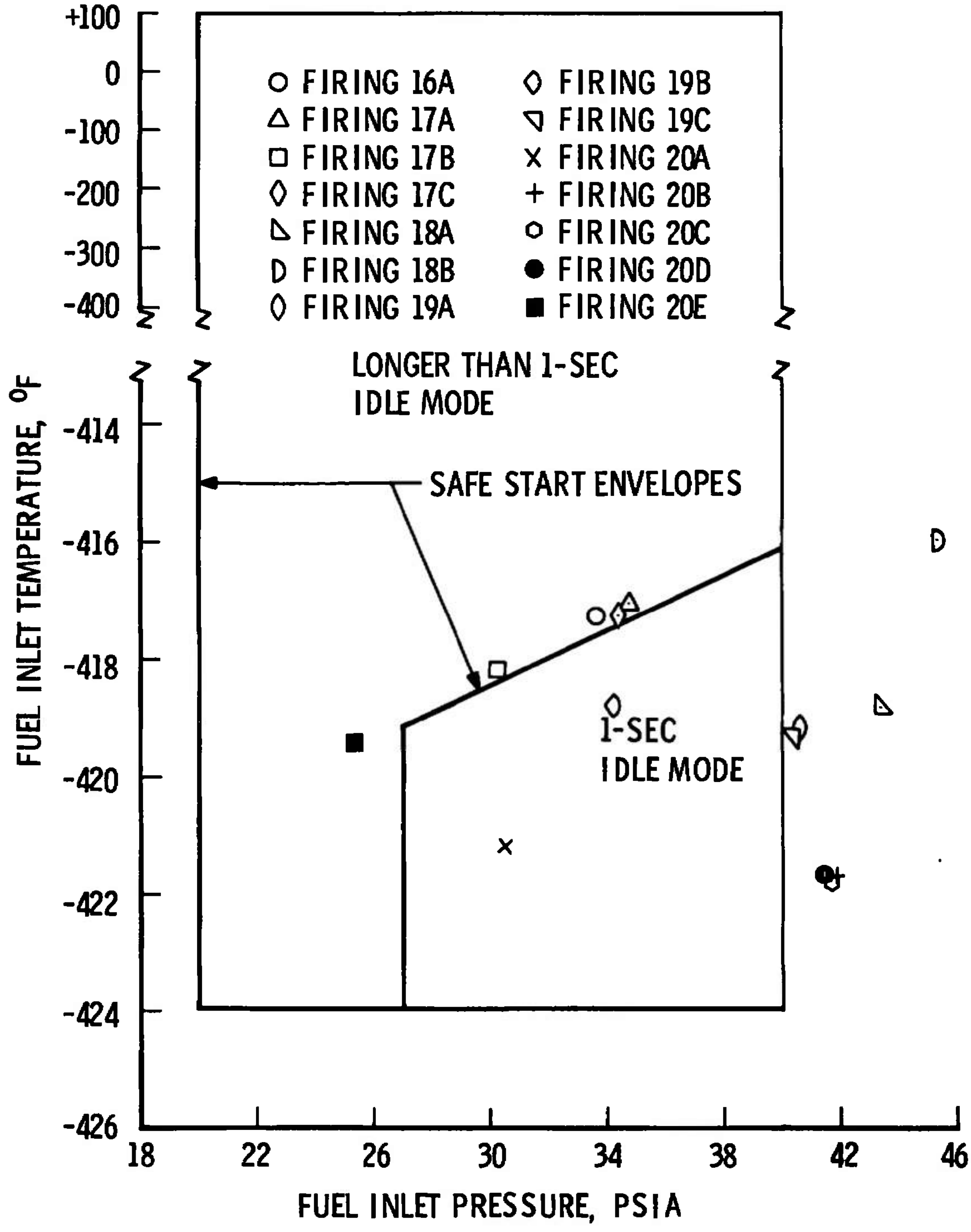


a. Engine Start Events



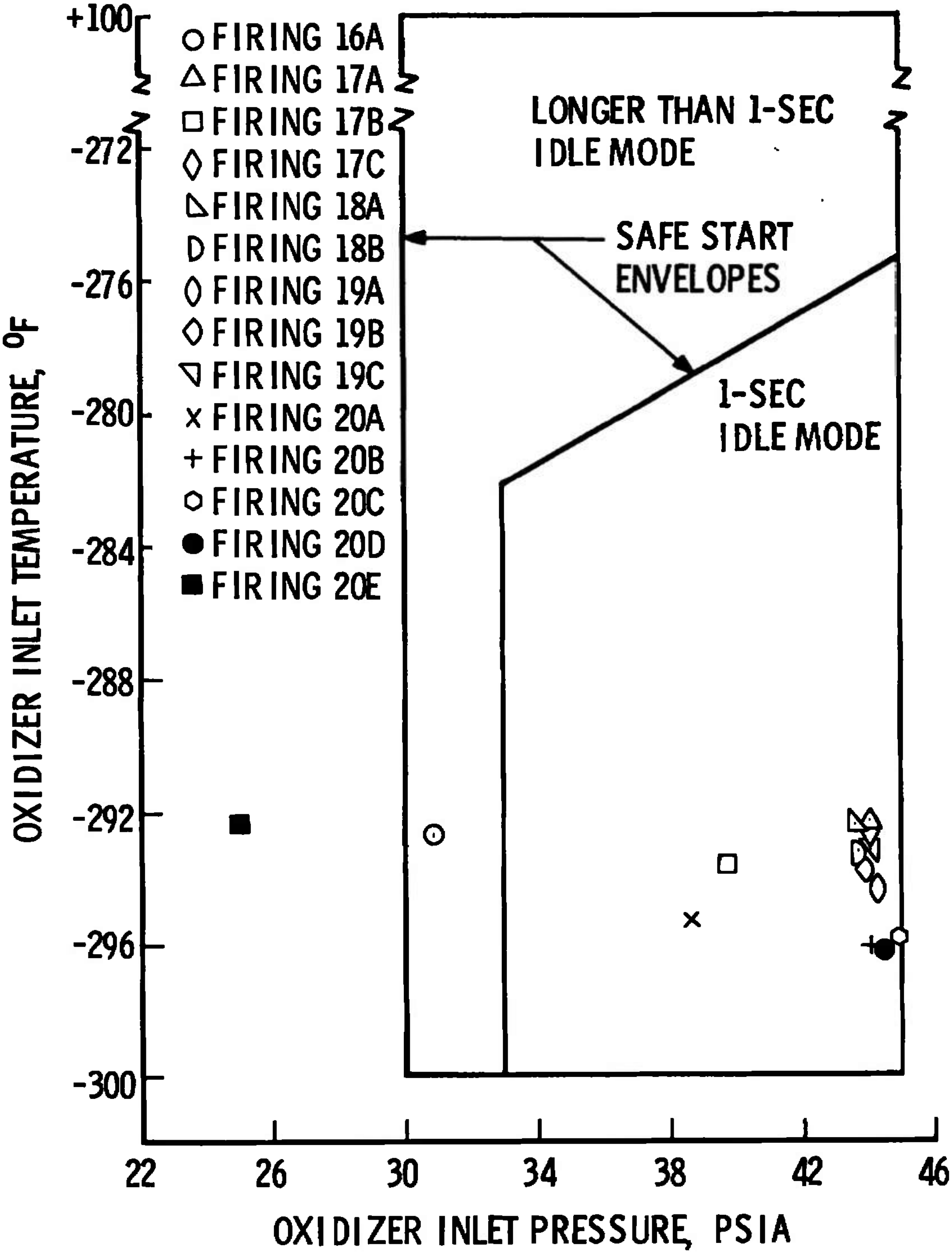
b. Engine Shutdown Events

Fig. 7 Engine Start and Shutdown Sequence

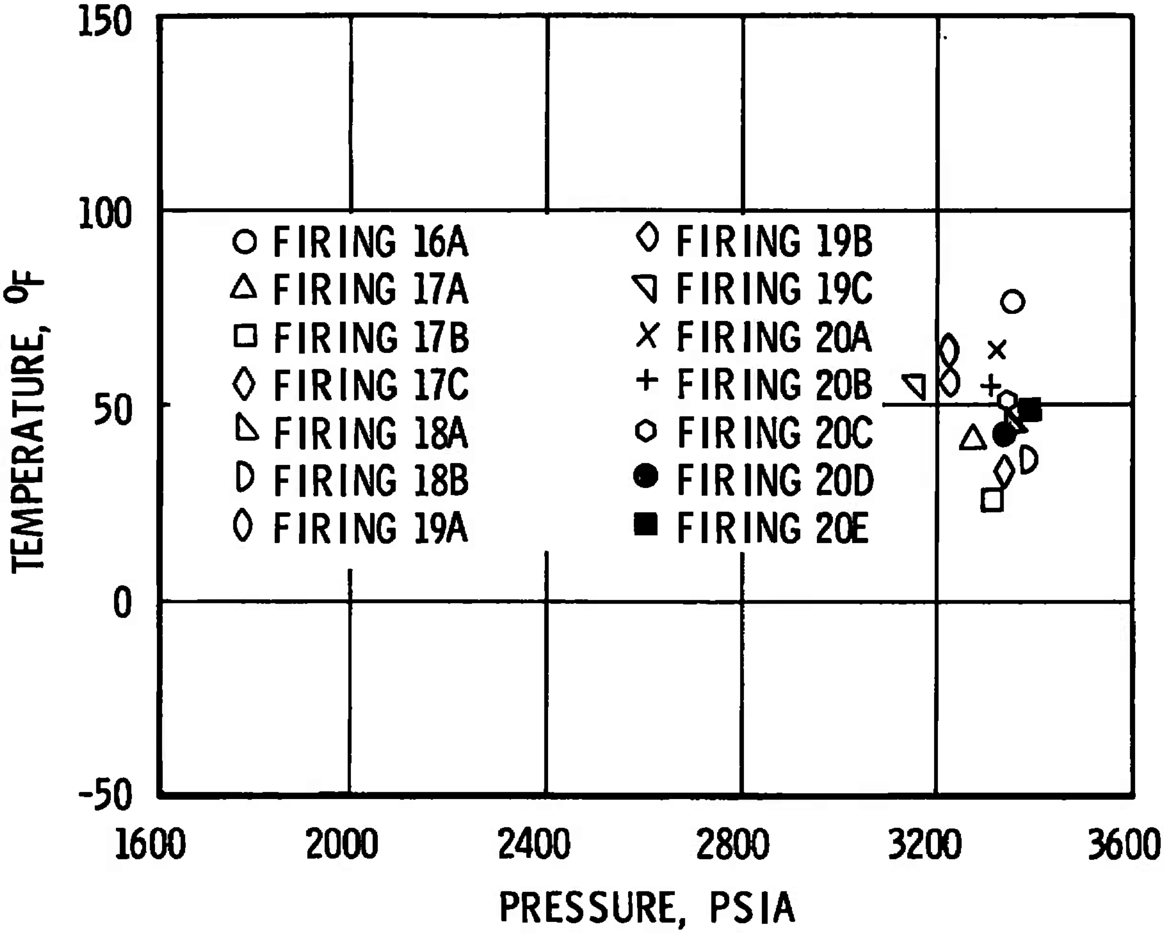


a. Fuel Pump

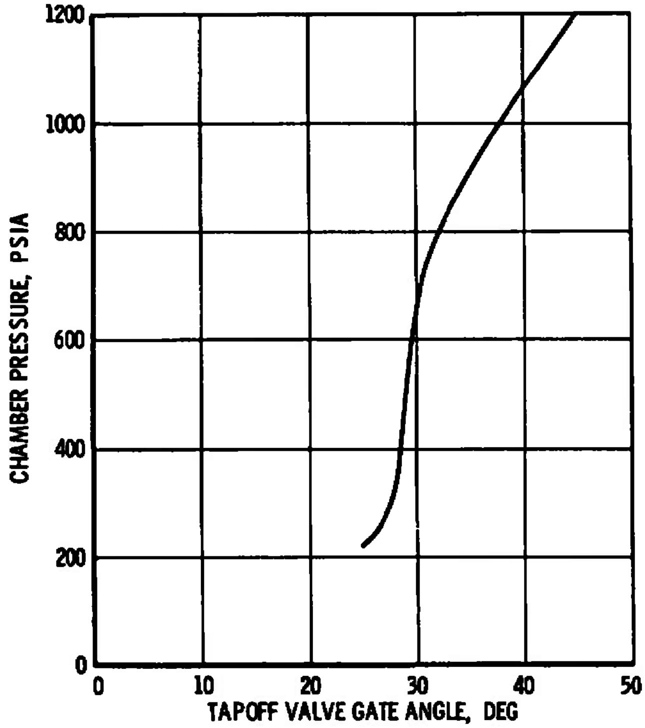
Fig. 8 Engine Start Conditions for Propellant Pump Inlets and Helium Tank



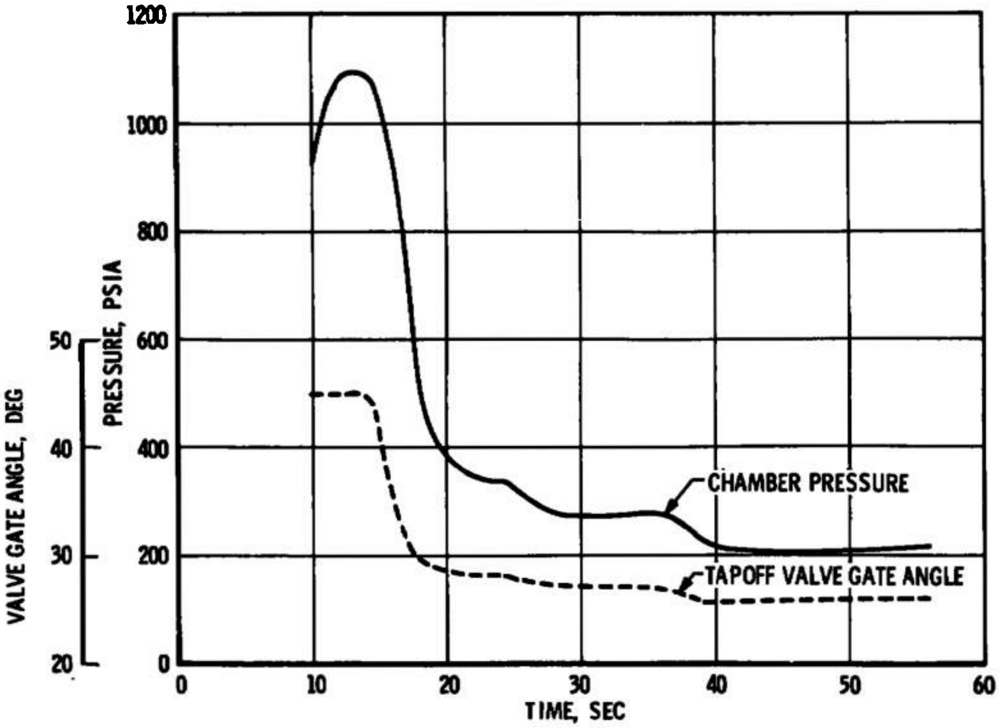
b. Oxidizer Pump
Fig. 8 Continued



c. Helium Tank
Fig. 8 Concluded

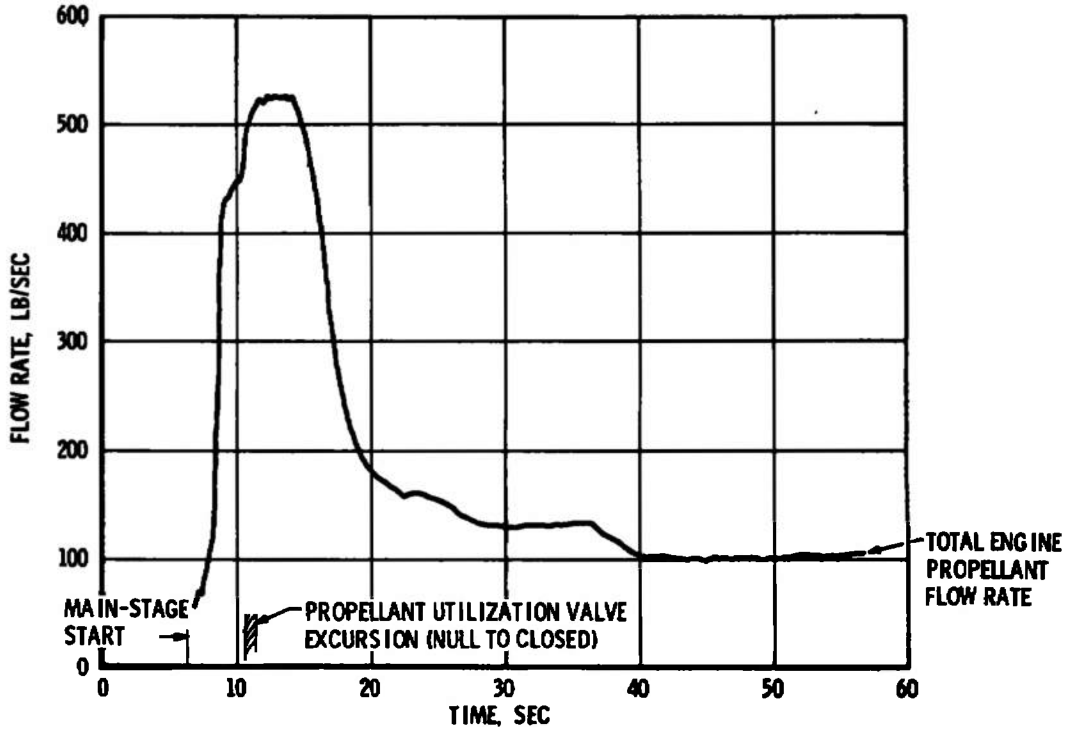


a. Angle versus Pressure

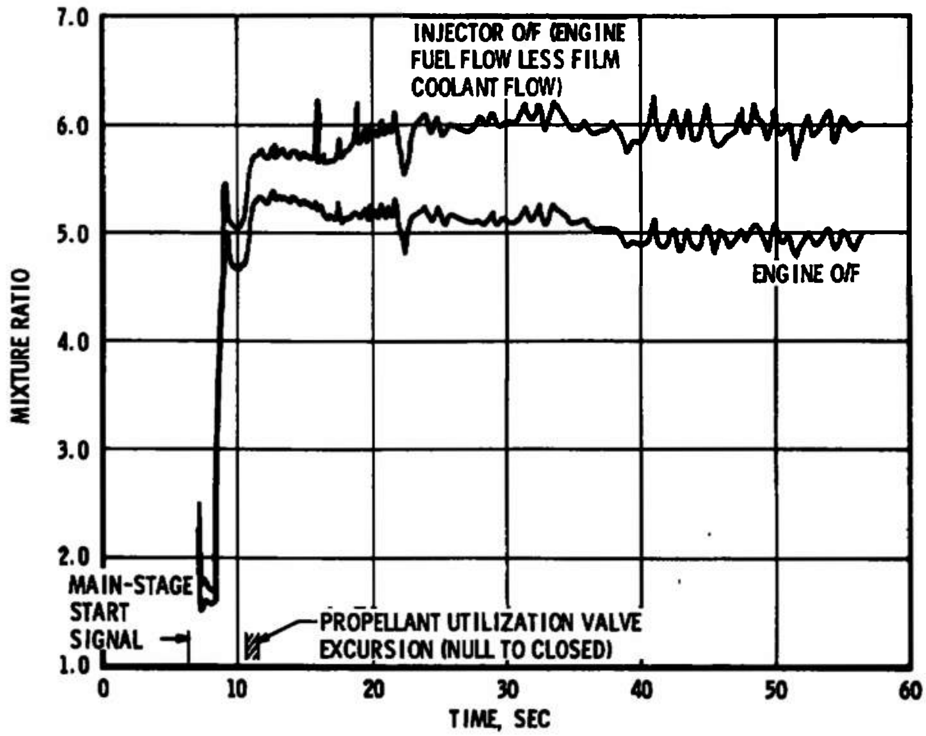


b. Chamber Pressure Response

Fig. 9 Tapoff Valve Gate Angle/Chamber Pressure Relationship



a. Total Propellant Flow Rate



b. Mixture Ratio

Fig. 10 Engine Total Propellant Flow Rate and Mixture Ratio during Throttling

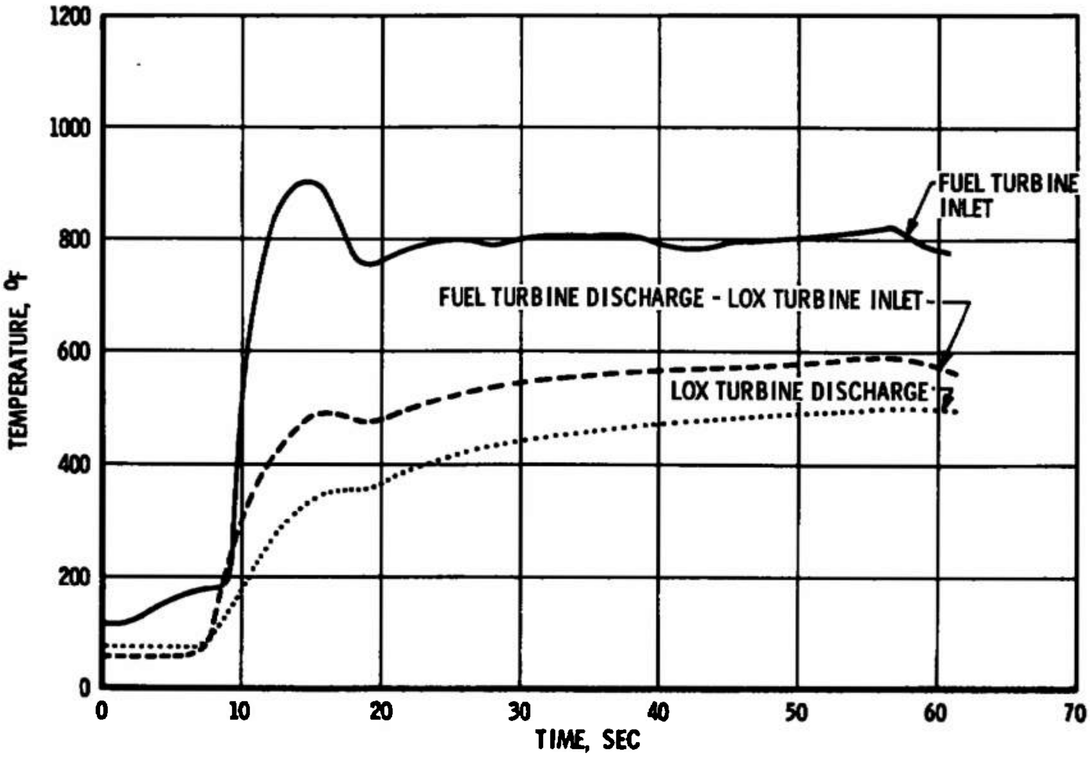


Fig. 11 Turbine System Temperatures

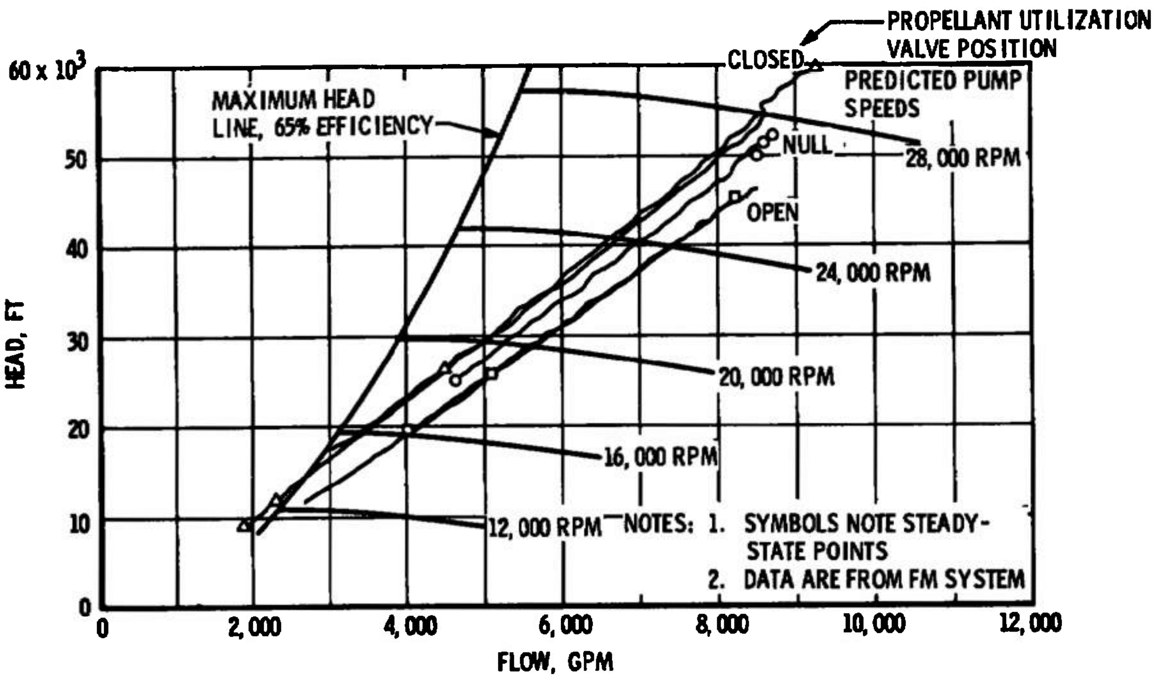


Fig. 12 Fuel Pump Performance during Throttling

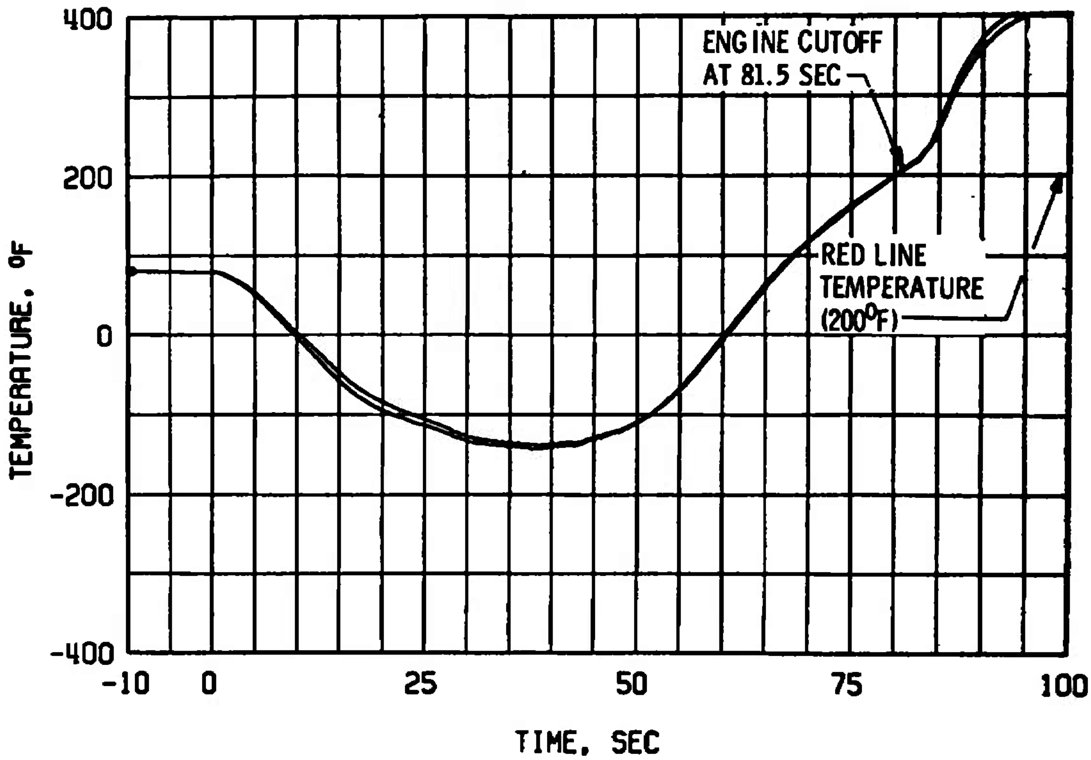


Fig. 13 Thrust Chamber Throat Temperature, Firing 16A

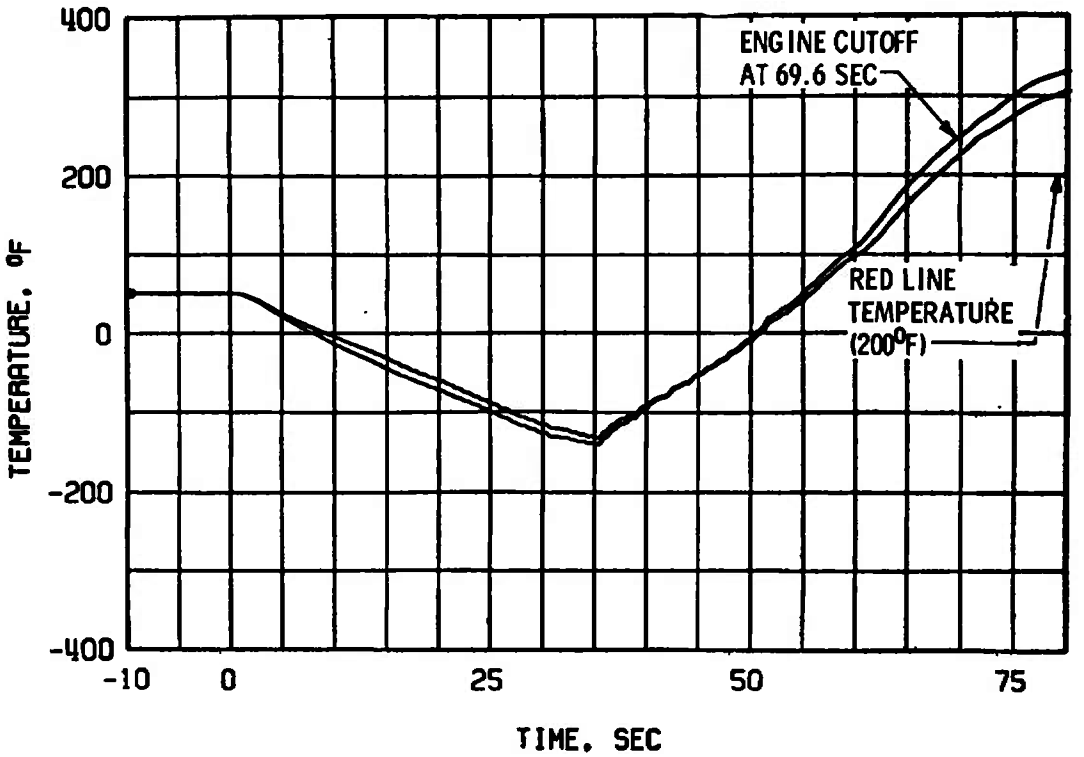
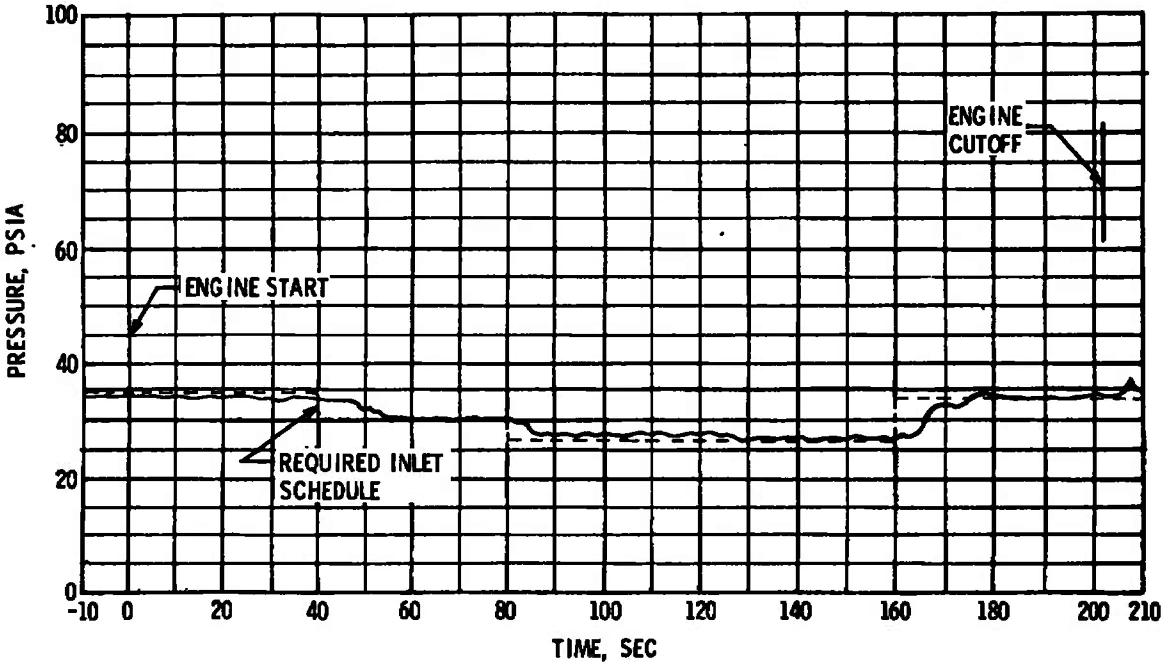
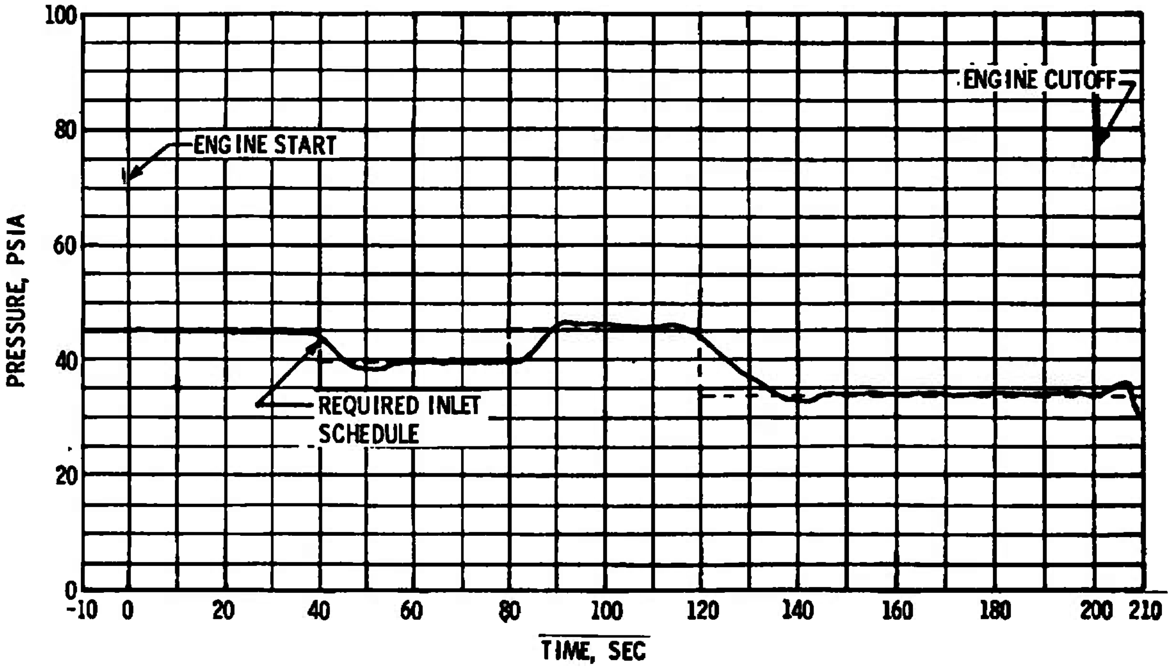


Fig. 14 Thrust Chamber Throat Temperature, Firing 17C



a. Fuel Pump



b. Oxidizer Pump

Fig. 15 Propellant Pump Inlet Pressure Schedule, Firing 19B

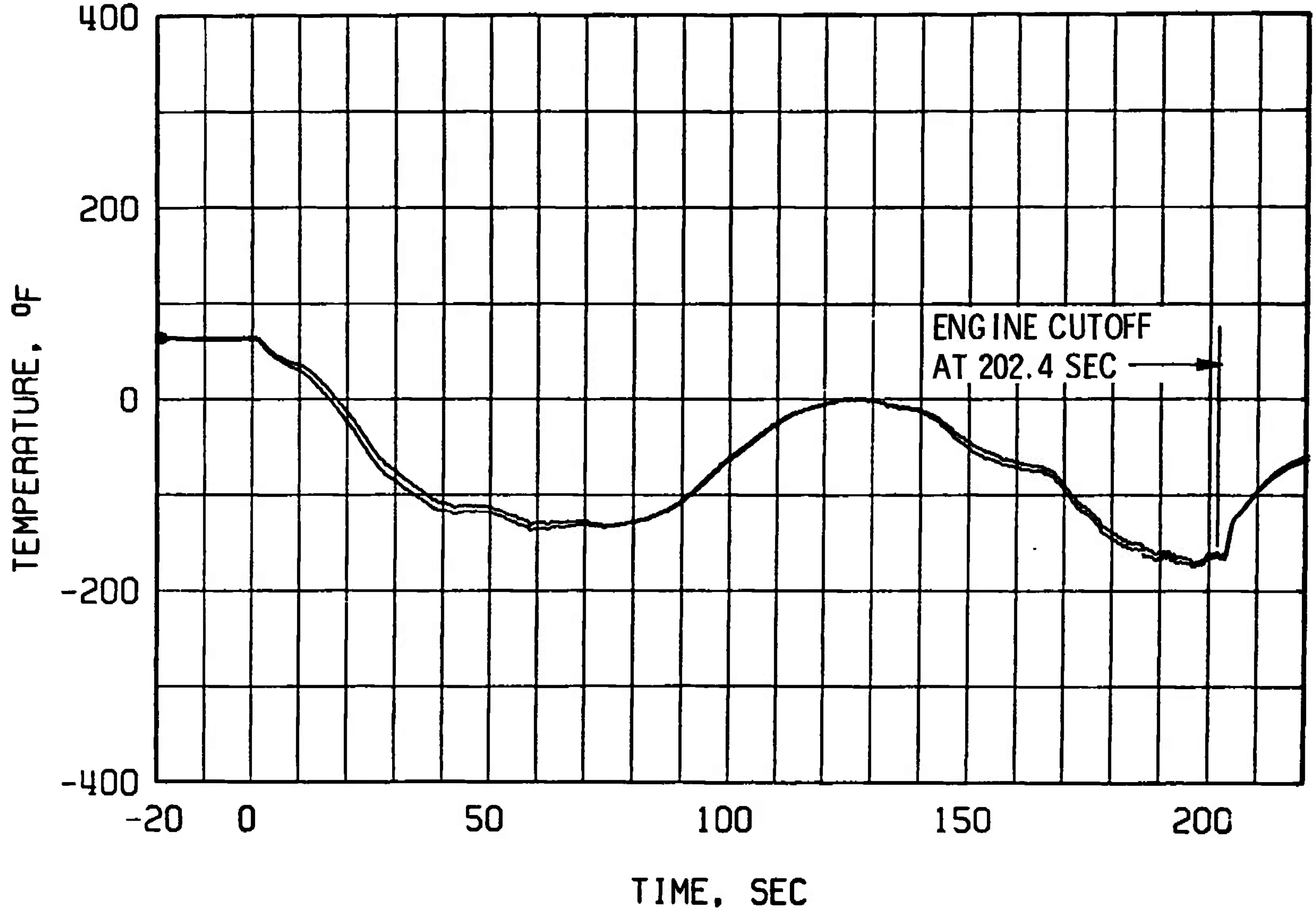


Fig. 16 Thrust Chamber Throat Temperature, Firing 19B

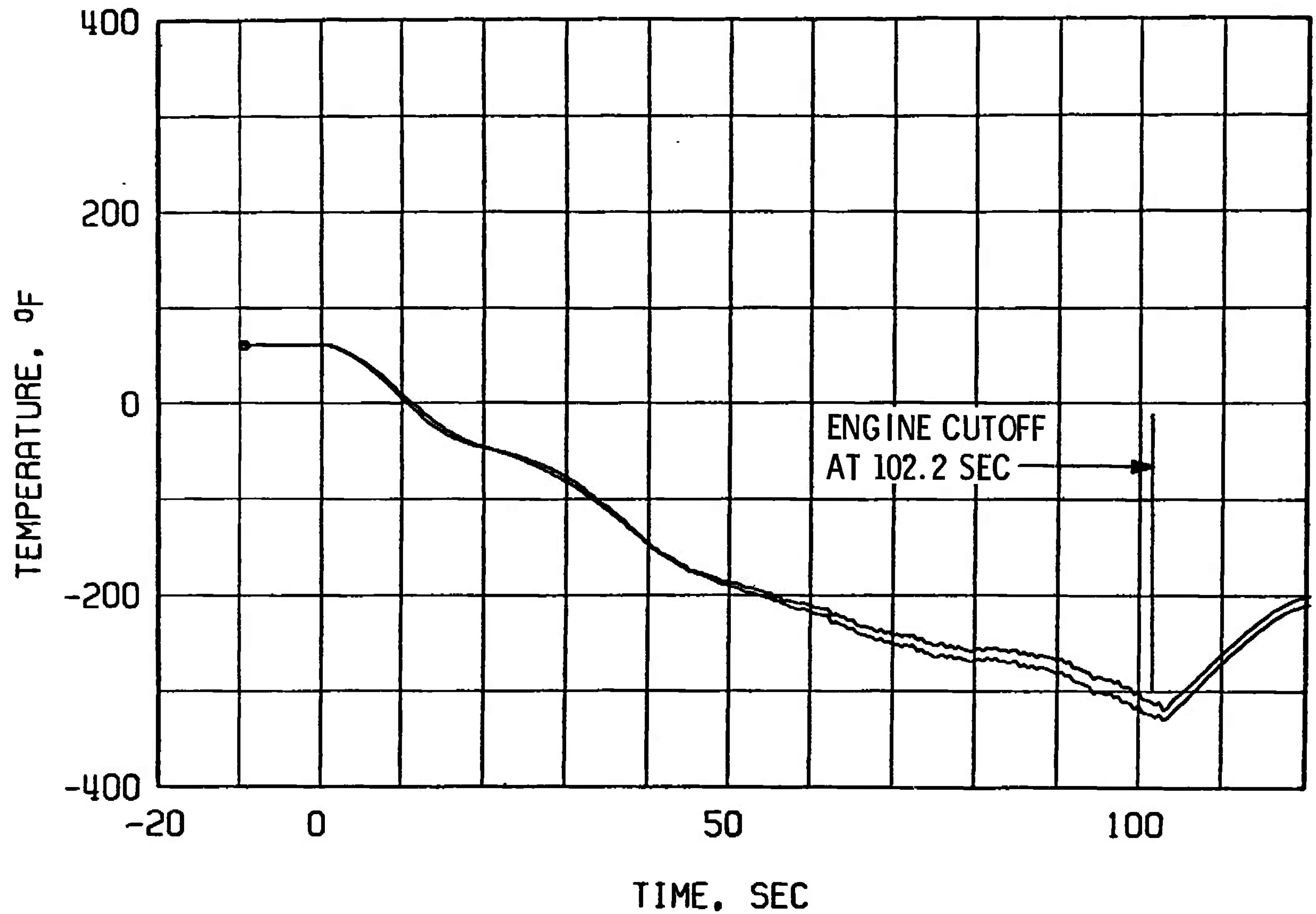


Fig. 17 Thrust Chamber Throat Temperature, Firing 20E

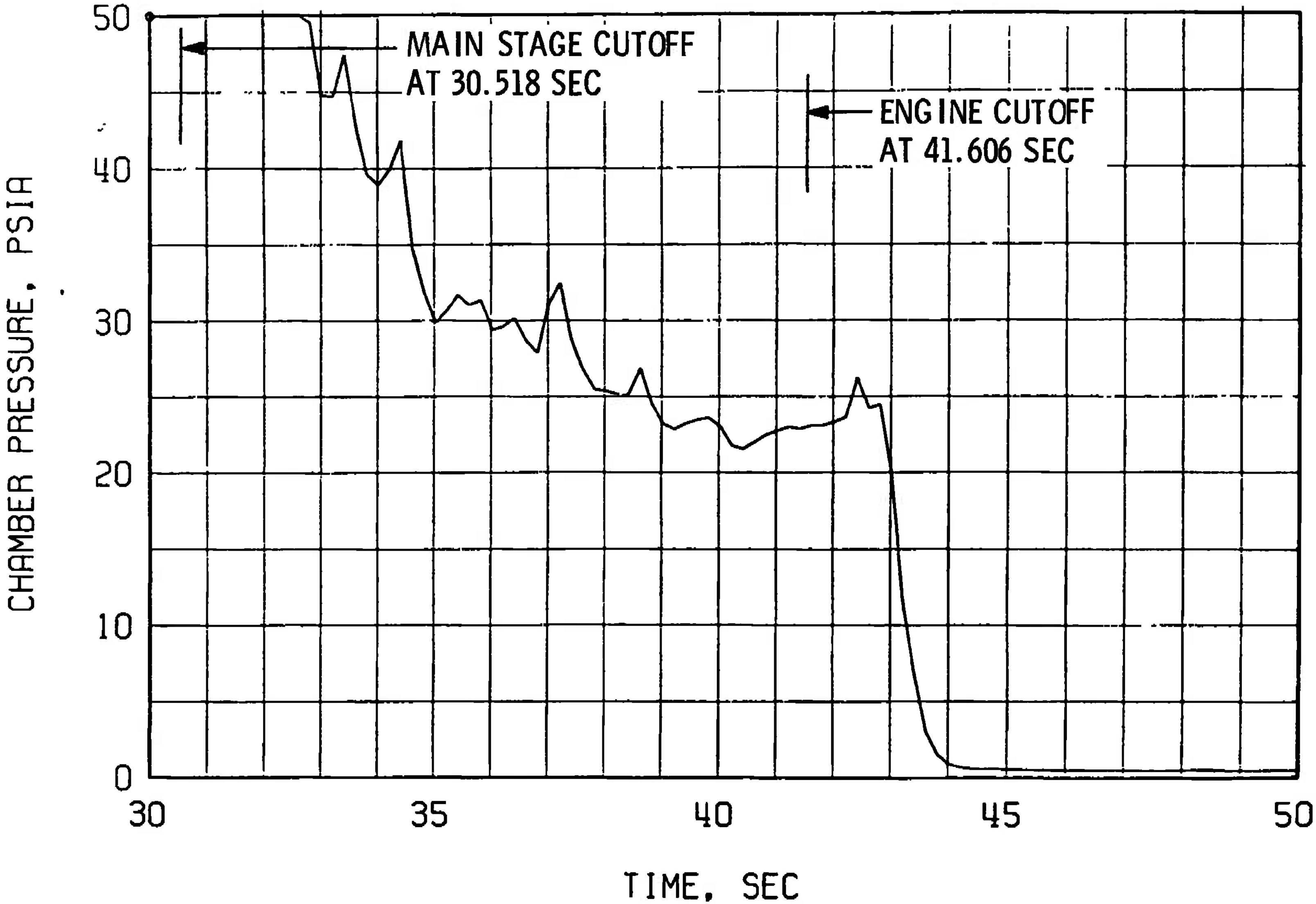
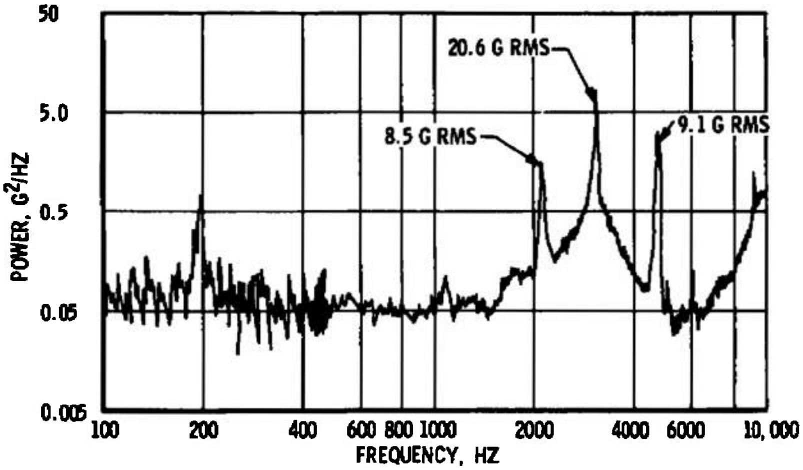
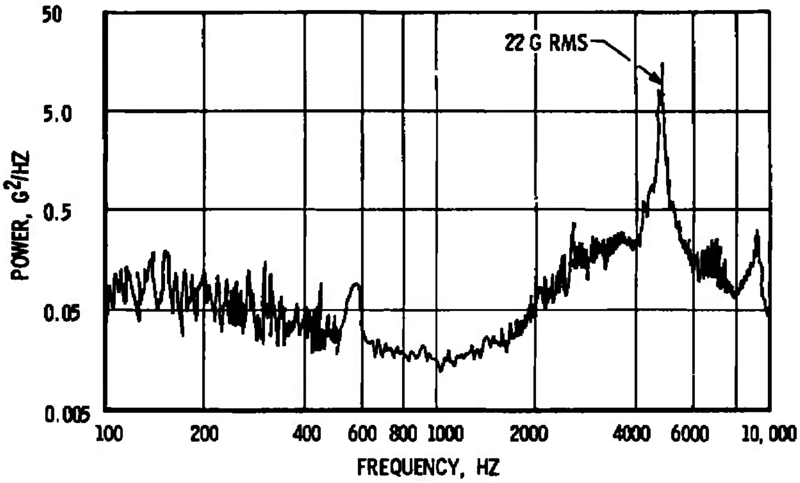


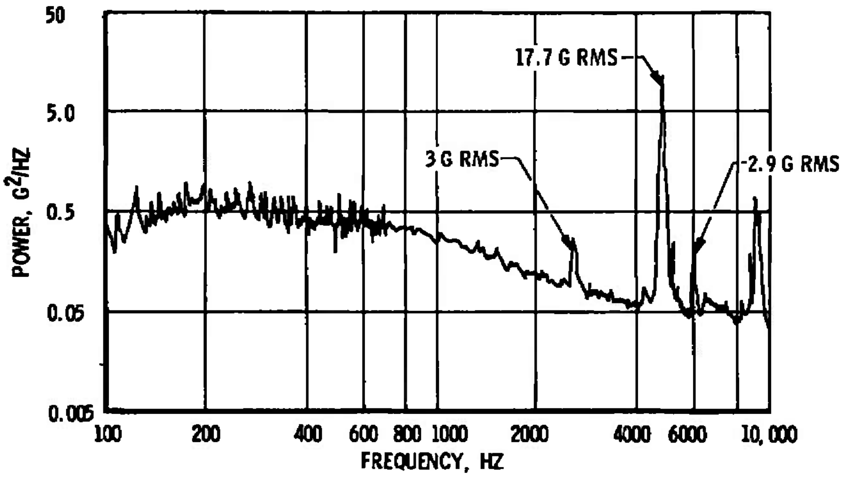
Fig. 18 Engine Combustion Chamber and Test Cell Pressure, Firing 20A, Post-Main-Stage Idle Mode



a. Oxidizer Pump Radial



b. Oxidizer Injector Dome 1



c. Oxidizer Injector Dome 2

Fig. 19 Power Spectral Density Analysis of Vibration Data, Firing 20A

TABLE I
MAJOR ENGINE COMPONENTS
(EFFECTIVE TEST J4-1001-16)

Part Name	P/N	S/N
Thrust Chamber Body Assembly	411082-201	2204449
Thrust Chamber Injector Assembly	XEOR936070	4087381
Augmented Spark Igniter Assembly	652050-61	4901625
Ignition Detector Probe 1	3243-2	016
Ignition Detector Probe 2	3243-2	003
Fuel Turbopump Assembly	461500-131	4901692
Oxidizer Turbopump Assembly	460430-11	4901664
Main Fuel Valve	411320-41	4901700
Main Oxidizer Valve	411225-81	4901679
Idle-Mode Valve	411385-31	4900955
Thrust Chamber Bypass Valve	411180-51	4900900
Hot Gas Tapoff Valve	557824-31	4901253
Propellant Utilization Valve	99-251455-X7	8900937
Electrical Control Package	503670-11X3	4901722
Engine Instrumentation Package	704641-11	4900428
Pneumatic Control Package	558330-21	4301005
Restart Control Assembly	503680-X	4901654
Helium Tank Assembly	NA5-260251	0005
Oxidizer Flowmeter	251216	4302737
Fuel Flowmeter	251225	4300940
Fuel Inlet Duct Assembly	409900-61	4300851
Oxidizer Inlet Duct Assembly	409899	4300863
Fuel Pump Discharge Duct	411082-57	2191043
Oxidizer Pump Discharge Duct	411082-27	2191053
Thrust Chamber Bypass Duct	411082-59	2190820
Fuel Turbine Exhaust Bypass Duct	307879-11	3838910
Hot Gas Tapoff Duct	411082-63	2190982
Solid-Propellant Turbine Starters Manifold	210921-31	3848757
Oxidizer Turbine Exhaust Duct	307887-31	3838870
Crossover Duct	307879-11	3838910

TABLE II
SUMMARY OF ENGINE ORIFICES

Orifice Name	Part Number	Diameter, in.	Test Effective	Comments
Oxidizer Turbine Bypass	RD251-4143	1.910	J4-1001-16	Delivered Part
Fuel Bypass	---	1.50	J4-1001-16	Delivered Part
Oxidizer Idle-Mode Supply Line	411092 411092	0.902 0.725	J4-1001-16 J4-1001-17	Delivered Part EWR 121343
Main Oxidizer Valve First Stage Gate Angle			J4-1001-16 J4-1001-17	10 deg 12.5 deg
Augmented Spark Igniter Oxidizer Supply Line	652050-19	0.100	J4-1001-16	Delivered Part
Augmented Spark Igniter Fuel Supply Line	---	---	J4-1001-16	Open Line
Film Coolant	411093-3	0.583	J4-1001-16	Delivered Part
Film Coolant Venturi		1.027 inlet 0.744 throat	J4-1001-16	$C_D = 0.97$
Propellant Utilization Valve Inlet		1.250	J4-1001-16	Delivered Part

TABLE III
ENGINE MODIFICATIONS
(BETWEEN TESTS J4-1001-16 AND -20)

Modification Number	Completion Date	Description of Modification
	TEST J4-1001-16*	3/10/70
EWR 121337	3/17/70	Install variable tapoff valve stop
EWR 121343	3/19/70	Install 0.725-in.-diam oxidizer idle-mode orifice
EWR 121335	3/11/70	Change main oxidizer gate first stage angle from 10 to 11 deg
EWR 121344	3/19/70	Change main oxidizer gate first stage angle from 11 to 12.5 deg
	TEST J4-1001-17	4/1/70
None		
	TEST J4-1001-18	4/15/70
None		
	TEST J4-1001-19	4/30/70
EWR 121267	5/ 8/70	Increase tapoff valve stop piston length by 0.036 in.
EWR 121271	5/12/70	Increase ASI # 1 probe immersion depth by 0.045 in.
	TEST J4-1001-20	5/19/70

*For Pretest 16 Engine Configuration, See Table I.

TABLE IV
ENGINE COMPONENT REPLACEMENTS
(BETWEEN TESTS J4-1001-16 AND -20)

Replacement	Completion Date	Component Replaced
	TEST J4-1001-16	3/10/70
P/N 99-461500-31 S/N R006-1	3/12/70	Fuel Pump P/N 461500-131 S/N 4901692 UCR# 013551
P/N 503670-11X3 S/N 4901723	3/19/70	Electrical Control Assembly P/N 503670-11X3 S/N 4901722 UCR# 013502
	TEST J4-1001-17	4/ 1/70
P/N 99-411385 S/N 8900867	4/13/70	Oxidizer Idle-Mode Valve P/N 411385-31 S/N 4900955 UCR# 013506
	TEST J4-1001-18	4/15/70
None		
	TEST J4-1001-19	4/30/70
P/N XEOR937048 S/N 4087387	5/ 5/70	Injector P/N XEOR936070 S/N 4087381
	TEST J4-1001-20	5/19/70

TABLE V
ENGINE PURGE AND COMPONENT CONDITIONING SEQUENCE

Purge	Requirement	SPTS Installed	Air On	Propellant Drop	Engine Start	Cutoff (Coast Period)	Propellant Drop	Restart	Cutoff (Last Firing)	Air-Off
Oxidizer dome and idle-mode diffuser	Nitrogen, 600 ± 25 psia 100 to 150°F at customer connect panel (150 scfm)								15 min	
Thrust chamber jacket, film coolant, and turbopump purges	Helium, 150 ± 25 psia 50 to 150°F at customer connect panel (125 scfm)		(**) (†)		(*)	15 min (**) (†)		(*)	30 min	
SPTS conditioning	Nitrogen, -50 to 140°F	1, 2, and 3				Remaining SPTS				
Main fuel valve conditioning	Helium, -300°F to ambient			††						

*Engine-supplied oxidizer pump intermediate seal cavity purge
**Anytime racility water is on
†30 min before propellant drop
††Initiate MFV conditioning 30 min before engine start for those firings with temperature requirements

TABLE VI
SUMMARY OF SIGNIFICANT TEST VARIABLES

TEST PERIOD/FIRING NO.	16A	17A	17B	17C	18A	18B	19A	19B	19C	20A	20B	20C	20D	20E
Fuel Pump Inlet Pressure, psia, at t-0	33.6	34.6	30.0	34.2	43.5	45.3	40.6	34.1	40.4	30.4	41.8	41.6	41.5	25.3
Oxidizer Pump Inlet Pressure, psia, at t-0	30.8	45.0	39.4	45.1	44.3	44.7	45.3	44.9	45.1	38.3	45.0	45.9	45.3	24.8
Main Oxidizer Valve First-Stage Position, deg	10.0	12.5	12.5	12.5	12.5	12.5	12.5	12.5	12.5	12.5	12.5	12.5	12.5	12.5
Propellant Utilization Valve Position at t-0	Null	Null	Null	Null	Null	Null	Null	Null	Null	Null	Null	Null	Null	Null
Fuel Bypass Line Orifice Diameter, in.	1.50	1.50	1.50	1.50	1.50	1.50	1.50	1.50	1.50	1.50	1.50	1.50	1.50	1.50
Oxidizer Idle-Mode Line Orifice Diameter, in.	0.902	0.725	0.725	0.725	0.725	0.725	0.725	0.725	0.725	0.725	0.725	0.725	0.725	0.725
Type Firing	Idle Mode	Throttle	Throttle	Idle Mode	Throttle	Throttle	Throttle Attempt	Idle Mode	Throttle	Main Stage	Throttle Attempt	Throttle Attempt	Throttle	Idle Mode
Propellant Utilization Valve Position during Throttle Operation	---	Open	Null	---	Closed	Null	---	---	Open	---	-	---	Closed	---

TABLE VII
SUMMARY OF TEST REQUIREMENTS AND RESULTS

Firing Number	J4-1001-16A Target	J4-1001-16A Actual	J4-1001-17A Target	J4-1001-17A Actual	J4-1001-17B Target	J4-1001-17B Actual	J4-1001-17C Target	J4-1001-17C Actual
Firing Date/Time of Day	--- / ---	3/10/70 / 1500	--- / ---	4/1/70 / 1310	--- / ---	4/1/70 / 1510	--- / - -	4/1/70 / 2008
Pressure Altitude at t-0, ft (Ref. 1)	100,000	03,000	100,000	94,000	100,000	103,000	100,000	00,000
Low Thrust Idle Mode Duration, sec	300	01.520	1	1.017	1	1.022	300	69.718
Mainstage Duration, sec	---	---	50	50.701	60	80.994	---	---
Post-Mainstage Low Thrust Idle Mode Duration, sec	---	---	- -	---	---	---	--	---
Fuel Pump Inlet Pressure at t-0, psia	34.0 ± 1.0	33.8	34.0 ± 1.0	34.0	30.0 ± 1.0	30.1	34.0 ± 1.0	34.3
Fuel Pump Inlet Temperature at t-0, °F	---	-417.4	---	-417.2	---	-410.3	--	-417.4
Fuel Tank Bulk Temperature at t-0, °F	-432.0 ± 0.4	-422.0	-422.0 ± 0.4	-432.0	433.0 ± 0.4	-422.0	422.0 ± 0.4	-422.5
Oxidizer Pump Inlet Pressure at t-0, psia	30.0 ± 1.0	30.8	46.0 ± 1.0	45.0	30.0 ± 1.0	30.4	45.0 ± 1.0	46.1
Oxidizer Pump Inlet Temperature at t-0, °F	---	-302.8	---	-302.0	---	-293.6	---	-292.0
Oxidizer Pump Bulk Temperature at t-0, °F	-295.0 ± 0.4	303.0	-203.0 ± 0.4	-203.4	-285.0 ± 0.4	-200.6	-293.0 ± 0.4	-203.0
Helium Tank Pressure at t-0, psia	+0 3450 - 200	3300	+0 3450 - 200	3380	---	3330	---	1660
Helium Tank Temperature at t-0, °F	--	74	---	40	---	35	---	33
Main Oxidizer Valve Temperature at t-0, °F	---	---	+0 -100 - 50	-93	+0 -100 - 50	80	--	07
Thrust Chamber Temperature at t-0, °F	Ambient	70	Ambient	50	Ambient	46	51	Ambient
Augmented Spark Igniter Ignition Delay, sec	30	0.779	1	0.007	1	0.603	30	0.620
Propellant in Engine Time, min	60	00	00	07	60	120	60	106
Propellant Utilization Valve Position/Time	Null t-0 / --- ---	Null t-0 / --- ---	Null t-0 / Open t + 6	Null t-0 / Open t + 7	Null 1 0 / Closed 1 + 40	Null t-0 / Closed t + 47	Null t-0 / --- ---	Null t-8 / --- ---
Solid Propellant Turbine Spinners: Part Number	---	---	---	08-803527-11	---	00 808637-11	---	---
Solid Propellant Turbine Spinners: Serial Number	---	---	---	RT000005	---	RT000000	- -	---
Solid Propellant Turbine Spinners: Temperature at t-0, °F	---	---	50 ± 10	45	60 ± 10	47	---	---
Solid Propellant Turbine Spinners: Burn Time, sec	- -	---	---	2.16	---	2.34	---	---
Solid Propellant Turbine Spinners: Maximum Pressure, psia	---	--	---	3336	---	3200	---	---

Firing Number	J4-1001-18A Target	J4-1001-18A Actual	J4-1001-18B Target	J4-1001-18B Actual	J4-1001-19A Target	J4-1001-19A Actual	J4-1001-19B Target	J4-1001-19B Actual	J4-1001-19C Target	J4-1001-19C Actual
Firing Date/Time of Day	--- / ---	4/15/70 / 1650	--- / ---	4/15/70 / 2215	--- / ---	4/30/70 / 1319	--- / - -	4/30/70 / 1601	--- / ---	4/30/70 / 2227
Pressure Altitude at t-0, ft (Ref. 1)	100,000	94,000	100,000	103,000	100,000	104,000	100,000	104,000	106,000	105,000
Low Thrust Idle Mode Duration, sec	1	1.013	1	1.010	1	1.016	300	202.076	6	6.870
Mainstage Duration, sec	60	60.161	60	60.308	35	1.073	---	---	35	26.053
Post-Mainstage Low Thrust Idle Mode Duration, sec	---	---	---	---	---	---	---	---	--	---
Fuel Pump Inlet Pressure at t-0, psia	40.0 (Minimum)	43.3	40.0 (Minimum)	43.1	40.0 (Minimum)	40.6	34.0 ± 1.0	34.1	40.0 (Minimum)	40.4
Fuel Pump Inlet Temperature at t-0, °F	---	-410.0	---	-416.2	---	-410.3	---	-416.9	---	-410.6
Fuel Tank Bulk Temperature at t-0, °F	-423.0 ± 0.4	-423.0	-422.0 ± 0.4	-423.0	-423.0 ± 0.4	-432.6	-422.0 ± 0.4	-432.0	-422.0 ± 0.4	-422.7
Oxidizer Pump Inlet Pressure at t-0, psia	43.0 ± 1.0	44.3	43.0 ± 1.0	44.7	43.0 ± 1.0	45.3	43.0 ± 1.0	44.0	43.0 ± 1.0	46.1
Oxidizer Pump Inlet Temperature at t-0, °F	---	-263.0	---	-293.3	---	-304.4	---	-293.0	--	-203.3
Oxidizer Pump Bulk Temperature at t-0, °F	-293.0 ± 0.4	-294.4	-203.0 ± 0.4	-395.6	-205.0 ± 0.4	-393.b	-285.0 ± 0.4	-294.6	-393.0 ± 0.4	-200.7
Helium Tank Pressure at t-0, psia	+0 3450 - 300	0380	---	2390	+0 6430 - 200	3230	---	3230	---	3170
Helium Tank Temperature at t-0, °F	---	46	---	30	---	63	---	63	---	54
Main Oxidizer Valve Temperature at t-0, °F	+0 -100 - 50	01	+0 -100 - 50	67	---	149	---	137	---	106
Thrust Chamber Temperature at t-0, °F	Ambient	33	Ambient	51	Ambient	60	Ambient	64	Ambient	64
Augmented Spark Igniter Ignition Delay, sec	1	0.766	1	0.617	1	4.610	30	0.770	3	0.607
Propellant in Engine Time, min	60	Oxidizer 03 / Fuel 440	00	50	50	139	60	214	50	344
Propellant Utilization Valve Position/Time	Null t-0 / Closed 1 + 6	Null t-0 / Closed t + 7	Null t-0 / --- ---	Null t-0 / --- ---	Null t-0 / Open t + 6.0	Null t-0 / --- ---	Null t-0 / --- ---	Null t-0 / --- ---	Null t-0 / Open 10.0	Null t-0 / Open t + 11
Solid Propellant Turbine Spinners: Part Number	---	00-603527-11	---	08-602327-11	---	00-803337-11	---	- -	---	659400-11
Solid Propellant Turbine Spinners: Serial Number	---	RT000010	---	RT000011	---	RT000012	---	---	---	RT000004
Solid Propellant Turbine Spinners: Temperature at t-0, °F	Ambient	46	Ambient	44	+100 ± 10	61	---	---	+106 ± 10	2
Solid Propellant Turbine Spinners: Burn Time, sec	---	3.44	---	2.44	---	2.20	---	---	---	3.30
Solid Propellant Turbine Spinners: Maximum Pressure, psia	---	3360	---	3280	---	3570	- -	---	---	3770

Firing Number	J4-1001-20A Target	J4-1001-20A Actual	J4-1001-20B Target	J4-1001-20B Actual	J4-1001-30C Target	J4-1001-30C Actual	J4-1001-20D Target	J4-1001-20D Actual	J4-1001-20E Target	J4-1001-20E Actual
Firing Date/Time of Day	--- / ---	3/10/70 / 12b1	--- / ---	5/10/70 / 1540	--- / ---	3/16/70 / 1015	--- / ---	5/16/70 / 1744	--- / ---	3/10/70 / 2306
Pressure Altitude at t-0, ft (Ref. 1)	100,000	100,000	100,000	101,000	100,080	100,000	100,000	101,000	100,000	100,000
Low Thrust Idle Mode Duration, sec	1	1.021	1	1.012	5	0.163	5	6.317	150	103.169
Mainstage Duration, sec	30	20.407	50	---	60	3.103	50	60.503	---	---
Post-Mainstage Low Thrust Idle Mode Duration, sec	10	11.060	---	---	---	---	---	---	---	---
Fuel Pump Inlet Pressure at t-0, psia	29.0 ± 1.0	30.4	40 (Minimum)	41.6	40 (Minimum)	41.6	40 (Minimum)	41.5	23 ± 1.0	35.3
Fuel Pump Inlet Temperature at t-0, °F	---	-431.2	---	-421.8	---	-421.9	---	-421.0	---	-410.3
Fuel Tank Bulk Temperature at t-0, °F	-423.0 ± 0.4	-422.8	-423.0 ± 0.4	-422.7	-422.0 ± 0.4	-422.6	-422.0 ± 0.4	-422.8	-423.0 ± 0.4	-422.8
Oxidizer Pump Inlet Pressure at t-0, psia	36.0 ± 1.0	30.3	43.0 ± 1.0	43.0	40.0 ± 1.0	43.6	46.0 ± 1.0	43.2	23 ± 1.0	35.0
Oxidizer Pump Inlet Temperature at t-0, °F	---	-205.4	---	-280.1	---	-305.0	---	-300.3	---	-294.6
Oxidizer Pump Bulk Temperature at t-0, °F	-395.0 ± 0.4	-304.3	-295.0 ± 0.4	-294.8	-305.0 ± 0.4	-203.6	-203.0 ± 0.4	-206.0	-203.0 ± 0.4	-300.3
Helium Tank Pressure at t-0, psia	+0 3430 - 300	3327	+0 3450 - 200	2336	+0 3450 - 300	3254	+0 3450 - 200	3330	+0 3450 - 200	3306
Helium Tank Temperature at t-0, °F	---	03	- -	54	---	50	---	41	---	46
Main Oxidizer Valve Temperature at t-0, °F	---	-3	---	2	---	-2	---	-1	---	22
Thrust Chamber Temperature at t-0, °F	Ambient	77	Ambient	03	Ambient	60	Ambient	00	Ambient	61
Augmented Spark Igniter Ignition Delay, sec	1	0.682	t + 1	1.550	t + 5	0.008	t + 3	1.060	t + 20	0.677
Propellant in Engine Time, min	00	03	60	49	00	33	60	80	60	63
Propellant Utilization Valve Position/Time	Null t-0 / Closed t + 6	Null t-0 / Closed t + 7.5	Null 1-0 / Closed t + 3	Null t-0 / --- ---	Null 1-0 / Closed t + 10	Null 1-0 / Closed t + 10.7	Null t-0 / Closed t + 10	Null t-0 / Closed t + 10	Null t-0 / --- ---	Null t-0 / --- --
Solid Propellant Turbine Spinners: Part Number	---	600400-11	---	---	---	650400-11	---	650400-11	---	---
Solid Propellant Turbine Spinners: Serial Number	---	RT006003	---	---	---	RT000000	---	RT000007	---	---
Solid Propellant Turbine Spinners: Temperature at t-0, °F	Ambient	68	---	---	Ambient	00	Ambient	-6	---	---
Solid Propellant Turbine Spinners: Burn Time, sec	---	2.10	---	---	---	2.10	---	2.74	---	---
Solid Propellant Turbine Spinners: Maximum Pressure, psia	- -	3290	---	---	---	3360	---	---	---	---

TABLE VIII
ENGINE VALVE TIMINGS

Test J4 1001-	Firing	Start																	
		Main Fuel Valve			Idle Mode Oxidizer Valve			Hot-Gas Tapoff Valve			Main Oxidizer Valve First Stage			Main Oxidizer Valve Second Stage			Thrust Chamber Bypass Valve		
		Time of Opening Signal	Valve Delay Time, sec	Valve Opening Time, sec	Time of Opening Signal	Valve Delay Time, sec	Valve Opening Time, sec	Time of Opening Signal	Valve Delay Time, sec	Valve Opening Time, sec	Time of Opening Signal	Valve Delay Time, sec	Valve Opening Time, sec	Time of Opening Signal	Valve Delay Time, sec	Valve Opening Time, sec	Time of Closing Signal	Valve Delay Time, sec	Valve Closing Time, sec
18	Final Sequence	0 00	0 060	0 150	0 00	0 260	0 065	---	---	---		----	---	---	--		---	---	---
	A	0 00	0 000	0 152	0 00	0.280	0 098	---	---		---	---	---	---	---	----	---	---	---
17	Final Sequence	0 00	0 057	0.070	0 00	0 141	0 042	1.035	0 157	0 050	1.036	0 001	0 030	2 922	0.180	0 049	2 922	0 208	0 800
	A	0 00	0 080	0 150	0 00	0 277	0 100	1 017	0.172	0 076	1 017	0 000	0 034	2.907	0.203	0.857	2.907	0 173	1 080
	B	0 00	0 000	0 090	0 00	0 105	0 085	1 022	0 184	0.003	1 022	0.128	0.038	2 014	0.235	0 805	2 914	0 198	1 037
	C	0 00	0 088	0 180	0 00	0 206	0 110	---	---	---			---	---	--		---	---	---
10	Final Sequence	0 00	0 000	0 145	0 00	0 249	0.062	1 015	0 143	0 080	1 015	0 080	0.030	2 000	0 175	0 910	2.900	0.195	0 820
	A	0 00	0 005	0 128	0.00	0 237	0 002	1 013	0.160	0.080	1 013	0 080	0.020	2.805	0 212	0 000	2 885	0.184	1.065

Test J4-1001	Firing	Shutdown														
		Main Oxidizer Valve			Hot Gas Tapoff Valve			Main Fuel Valve			Idle-Mode Oxidizer Valve			Thrust Chamber Bypass Valve		
		Time of Signal	Valve Delay, sec	Valve Closing, sec	Time of Signal	Valve Delay, sec	Valve Closing, sec	Time of Signal	Valve Delay, sec	Valve Closing, sec	Time of Signal	Valve Delay, sec	Valve Closing sec	Time of Signal	Valve Delay, sec	Valve Opening sec
10	Final Sequence	---	---		---	---	---	---	0.072	0.240	---	0 071	0 170	---	---	---
	A	---	---	---	---	---	---	81 528	0 072	0.242	81 520	0 100	0 231	---	---	---
17	Final Sequence	---	0.088	0 140		0 098	0 110	---	0 083	0 235	---	0 080	0 165	---	0 200	0 222
	A	80 718	0 007	0 153	60 710	0 097	0 001	00 718	0 084	0.260	60 718	0.110	0 234	00.718	0 350	0 208
	B	81 016	0.097	0.155	81 010	0.091	0 121	61.016	0 094	0 284	81 019	0.130	0.242	61 018	0 388	0.208
	C	---	---	--		---	---	80.710	0 074	0 250	09 718	0 006	0.262	---	---	---
18	Final Sequence	---	0 005	0 136	---	0.092	0 085	---	0.076	0 230		0 080	0 158	---	0 209	0.210
	A	61 104	0 000	0 144	61 194	0 100	0.006	61 194	0.100	0 263	61 194	0.080	0.165	01.194	0 344	0.213

NOTES:
1. All valve signal times are referenced to 1 0
2. Valve delay time is the time required fc initial valve movement after the valve "open" or "closed" solenoid has been energized.
3. Final sequence check is conducted without propellants and within 12 hr before testing.
4. Data are reduced from oscillograph.

TABLE VIII (Continued)

Test J4 1001-	Firing	Start																	
		Main Fuel Valve			Idle-Mode Oxidizer Valve			Hot-Gas Tapoff Valve			Main Oxidizer Valve First Stage			Main Oxidizer Valve Second Stage			Thrust Chamber Bypass Valve		
		Time of Opening Signal	Valve Delay Time, sec	Valve Opening Time, sec	Time of Opening Signal	Valve Delay Time, sec	Valve Opening Time, sec	Time of Opening Signal	Valve Delay Time, sec	Valve Opening Time, sec	Time of Opening Signal	Valve Delay Time, sec	Valve Opening Time, sec	Time of Opening Signal	Valve Delay Time, sec	Valve Opening Time, sec	Time of Closing Signal	Valve Delay Time, sec	Valve Closing Time, sec
18	B	0.00	0 058	0.089	0.00	0 152	0 043	1 018	0.153	0.082	1.018	0.081	0 028	2,000	0 240	0 922	2 980	0.105	1 020
19	Final Sequence	0.00	0 082	0.080	0 00	0 151	0 027	1.027	0 188	8 078	1 027	0 085	0.028	2.020	0 179	0 850	2.020	0.210	0.808
	A	0 00	0.150	0 102	0 00	0.364	0.068	1.018	0 185	8 077	1 018	0 087	0 030	---	---	---	---	---	---
	B	0 00	0 112	0 127	0 00	0.245	0.043	---	---	---	---	---	---	---	---	---	---	---	---
	C	0.00	0.081	0.060	0 00	0 158	0 044	8 870	0 181	0 080	6.870	0 080	0 025	8.754	0.230	0.917	8 754	0.187	1 055
20	Final Sequence	0 00	0 060	0 000	0 00	0 145	0 030	1 018	0 148	0.040	1 010	0 078	0.036	2.012	0 160	0.860	2 012	0.280	0 852
	A	0 00	0.092	0 000	0 00	0 170	0 045	1 021	0 180	0.078	1 021	0 085	0.020	2 012	0.212	0.918	2 012	0.180	1 088
	B	0 00	0,080	0.088	0.00	0 170	0 045	---	-		--	---	---	---	---	---	---	---	---

Test J4-1001-	Firing	Shutdown														
		Main Oxidizer Valve			Hot Gas Tapoff Valve			Main Fuel Valve			Idle-Mode Oxidizer Valve			Thrust Chamber Bypass Valve		
		Time of Signal	Valve Delay, sec	Valve Closing, sec	Time of Signal	Valve Delay, sec	Valve Closing, sec	Time of Signal	Valve Delay, sec	Valve Closing, sec	Time of Signal	Valve Delay, sec	Valve Closing sec	Time of Signal	Valve Delay, sec	Valve Opening sec
18	B	81 224	0 087	0 145	81 224	0.092	0 087	61 224	0.100	0 270	81 224	0 085	0 185	81 224	0.253	0.208
10	Final Sequence	---	0.084	0.140	--	0.082	0.170	---	0.055	0 122	---	0 086	0 240	---	0.308	0.210
	A	2 080	0 048	0.040	2 800	0 085	0 137	2.080	0.103	0 355	2 989	0 090	0 188	---	-	---
	B	---	---	---	---	---	---	202 378	0 088	0 432	202 378	0.004	0.100	---	---	---
	C	34 023	0 080	0.142	34.922	0.000	0 082	34.022	0 108	0.290	34.023	0 089	0.178	34 023	0 342	0 214
20	Final Sequence	---	0.072	0.138	---	0.002	0.087	---	0 082	0.228	---	0 064	0 113	---	0 285	0 224
	A	30 818	0.083	0.152	30 518	0 073	0.100	41 807	0.004	0.222	41.807	0.070	0 184	30 518	0 352	0.200
	B	---	---	---	---	---	---	1 012	0 000	0,266	1 012	0 088	0 180	---	..	-

NOTES. 1. All valve signal times are referenced to t-0.

2 Valve delay time is the time required for initial valve movement after the valve "open" or "closed" solenoid has been energized.

3 Final sequence check is conducted without propellants and within 12 hr before testing.

4. Data are reduced from oscillograph.

TABLE VIII (Concluded)

Firing Number J4-1001-	Start																	
	Main Fuel Valve			Idle Mode Oxidizer Valve			Hot Gas Tapoff Valve			Main Oxidizer Valve First Stage			Main Oxidizer Valve Second Stage			Thrust Chamber Fuel Bypass Valve		
	Time of Open Signal	Valve Delay Time, sec	Valve Open Time, sec	Time of Open Signal	Valve Delay Time, sec	Valve Open Time, sec	Time of Open Signal	Valve Delay Time, sec	Valve Open Time, sec	Time of Open Signal	Valve Delay Time, sec	Valve Open Time, sec	Time of Open Signal	Valve Delay Time, sec	Valve Open Time, sec	Time of Closing Signal	Valve Delay Time, sec	Valve Closing Time, sec
20C	0.00	0.073	0.081	0.00	0.167	0.038	9.192	0.160	0.070	9.192	0.086	0.030	11.077	0.257	0.900	11.077	0.198	1.063
D	0.00	0.085	0.105	0.00	0.180	0.045	6.320	0.155	0.078	6.320	0.084	0.032	8.205	0.213	0.886	8.205	0.205	1.038
E	0.00	0.080	0.058	0.00	0.150	0.045	---	---	---	---	---	---	---	---	---	---	---	---

Firing Number J4-1001-	Shutdown														
	Main Oxidizer Valve			Hot Gas Tapoff Valve			Main Fuel Valve			Idle Mode Oxidizer Valve			Thrust Chamber Fuel Bypass Valve		
	Time of Closing Signal	Valve Delay Time, sec	Valve Closing Time, sec	Time of Closing Signal	Valve Delay Time, sec	Valve Closing Time, sec	Time of Closing Signal	Valve Delay Time, sec	Valve Closing Time, sec	Time of Closing Signal	Valve Delay Time, sec	Valve Closing Time, sec	Time of Opening Signal	Valve Delay Time, sec	Valve Opening Time, sec
20C	12.390	0.060	0.165	12.390	0.076	0.153	12.390	0.107	0.330	12.390	0.086	0.170	12.390	0.227	0.237
D	56.820	0.093	0.142	56.820	0.102	0.070	56.820	0.110	0.335	56.820	0.090	0.171	56.820	0.362	0.217
E	---	---	---	---	---	---	102.189	0.091	0.296	102.189	0.073	0.175	---	---	---

NOTES: 1. All valve signal times are referenced to t-0.

2. Valve delay time is the time required for initial valve movement after the valve "open" or "closed" solenoid has been energized.

3. Final sequence check is conducted without propellants and within 12 hr before testing.

4. Data reduced from oscillograph.

APPENDIX III
INSTRUMENTATION SUMMARY

The instrumentation for AEDC Tests J4-1001-16, -17, -18, -19, and -20 is tabulated in Table III-1. The location of selected major engine instrumentation is shown in Fig. III-1.

TABLE III-1
INSTRUMENTATION LIST

AEDC Code	Parameter	Tap Number	Range	Digital Data System	Magnetic Tape	Oscillo-graph	Strip Chart	Event Recorder	X-Y Plotter
	Event								
EOCO	Observer Cutoff Signal		On/Off					x	
EOPCO	Oxidizer Pump Overspeed Cutoff Signal		On/Off					x	
EOPVC	Oxidizer Prevalve Closed Limit		On/Off	x				x	
EOPVO	Oxidizer Prevalve Open Limit		On/Off	x				x	
EOTCO	Fuel Turbine Over-Temperature Cutoff		On/Off					x	
ERASIS-1	Augmented Spark Igniter Spark Rate -1		On/Off			x			
ERASIS-2	Augmented Spark Igniter Spark Rate -2		On/Off			x			
ES1M1	No. 1 Solid-Propellant * Turbine Starter Exploding Bridge Wire Monitor 1		On/Off	x		x			
ES1M2	No. 1 Solid-Propellant * Turbine Starter Exploding Bridge Wire Monitor 2		On/Off	x		x			
ES2M1	No. 2 Solid-Propellant * Turbine Starter Exploding Bridge Wire Monitor 1		On/Off	x		x			
ES2M2	No. 2 Solid-Propellant * Turbine Starter Exploding Bridge Wire Monitor 2		On/Off	x		x			
ES3M1	No. 3 Solid-Propellant * Turbine Starter Exploding Bridge Wire Monitor 1		On/Off	x		x			
ES3M2	No. 3 Solid-Propellant * Turbine Starter Exploding Bridge Wire Monitor 2		On/Off	x		x			
ESAMCO	Stall Approach Monitor Cutoff		On/Off					x	
ESPTS	Solid-Propellant Turbine Starter Initiated		On/Off					x	
ESR-1	Solid-Propellant Turbine * Starter 1 Ready		On/Off	x		x		x	
ESR-2	Solid-Propellant Turbine * Starter 2 Ready		On/Off	x		x		x	
ESR-3	Solid-Propellant Turbine * Starter 3 Ready		On/Off	x		x		x	
ESTCO	Start "OK" Timer Cutoff Signal		On/Off					x	
ETCBC	Thrust Chamber Bypass Valve Closed		On/Off					x	
ETCBO	Thrust Chamber Bypass Valve Open		On/Off					x	
EVSC-1	Vibration Safety Counts -1		On/Off			x			
EVSC-2	Vibration Safety Counts -2		On/Off			x			
EVSC-3	Vibration Safety Counts -3		On/Off			x			
	Flows, gpm								
QF-1	Engine Fuel	PFF	0 to 11,000	x					
QF-2	Engine Fuel	PFFa	0 to 11,000	x	x	x			x
QF-3	Engine Fuel	PFF	0 to 11,000			x			
QFRP	Fuel Recirculation System * † ††		0 to 160	x					
QO-1	Engine Oxidizer	POF	0 to 3,600	x					
QO-2	Engine Oxidizer	POFa	0 to 3,600	x	x	x			
QO-3	Engine Oxidizer	POF	0 to 3,600			x			
QORP*	Oxidizer Recirculation System * † ††		0 to 100	x	x	x			

TABLE III-1 (Continued)

AEDC Code	Parameter	Tap Number	Range	Digital Data System	Magnetic Tape	Oscillo-graph	Strip Chart	Event Recorder	X-Y Plotter
	Forces, lbf								
FSP-1	Side Load (Pitch)		±20,000	x	x	x			
FSY-1	Side Load (Yaw)		±20,000	x	x	x			
FZ-H	Axial Thrust		0 to 300,000	x	x	x			
FZ-L	Axial Thrust		±10,000	x	x	x			
	Position, Percent Open								
LFBT	Thrust Chamber Bypass Valve		0 to 100	x		x			
LFVT	Main Fuel Valve		0 to 100	x		x			
LIMT	Idle-Mode/Augmented Spark Igniter Oxidizer Valve		0 to 100	x		x			
LOVT	Main Oxidizer Valve		0 to 100	x		x			
LPUTOP	Propellant Utilization Valve		5 volts	x		x	x		
LTCV	Thrust Control *		5 volts	x		x	x		
LTVT	Hot Gas Tapoff Valve		0 to 100	x		x			
	Pressure, psia								
PA-1	Test Cell		0 to 0.5	x					
PA-2	Test Cell		0 to 1.0	x					
PA-3	Test Cell		0 to 5.0	x		x	x		
PC-1P	Thrust Chamber	CG1	0 to 1500	x					
PC-2P	Thrust Chamber *	CG1a	0 to 1500	x		x	x		
PC-2PL	Thrust Chamber	CG1a-1	0 to 50	x		x	x		
PCSPTS-1	Solid-Propellant * Turbine Starter Chamber 1	PTS-1	0 to 5000	x		x			
PCSPTS-2	Solid-Propellant * Turbine Starter Chamber 2	PTS-2	0 to 5000	x		x			
PCSPTS-3	Solid-Propellant * Turbine Starter Chamber 3	PTS-3	0 to 5000	x		x			
PFASIJ	Augmented Spark Igniter Fuel Injector	CF4	0 to 2000	x					
PFASIJ-L	Augmented Spark Igniter Fuel Injector	CF4	0 to 50	x					
PFCVI	Film Coolant Venturi Inlet	CF7	0 to 2000	x					
PFCVI-L	Film Coolant Venturi Inlet	CF7	0 to 50	x					
PFCVT	Film Coolant Venturi Throat	CF6	0 to 2000	x					
PFCVT-L	Film Coolant Venturi Throat	CF6	0 to 50	x					
PFJ-1	Fuel Injection	CF2	0 to 1500	x		x			
PFJ-1L	Fuel Injection	CF2	0 to 50	x					
PFMI	Fuel Jacket Manifold Inlet	CF1	0 to 2000	x					
PFPBC	Fuel Pump Balance Piston Cavity	PF5	0 to 2000	x		x	x		
PFPBS	Fuel Pump Balance Piston Sump	PF4	0 to 1000	x		x	x		
PFPD-1L	Fuel Pump Discharge	PF3	0 to 50	x					
PFPD-1P	Fuel Pump Discharge	PF3	0 to 2500	x	x	x			x***
PFPD-2	Fuel Pump Discharge *†		0 to 3000	x					x
PFPI-1	Fuel Pump Inlet	PF1	0 to 100	x			x		x
PFPI-2	Fuel Pump Inlet		0 to 100	x					x
PFPI-3	Fuel Pump Inlet	PF1a	0 to 100	x	x	x			x
PFPRB	Fuel Pump Rear Bearing Coolant	PF7	0 to 1000	x					

TABLE III-1 (Continued)

AEDC Code	Parameter	Tap Number	Range	Digital Data System	Magnetic Tape	Oscillograph	Strip Chart	Event Recorder	X-Y Plotter
	Pressure, psia								
PFRPO	Fuel Recirculation Pump Outlet * † ††		0 to 100	x					
PFRPR	Fuel Recirculation Pump Return * † ††		0 to 50	x					
PFTI	Fuel Turbine Inlet	TG1	0 to 1000	x		x			
PFUT	Fuel Ullage Tank		0 to 100	x					
PFUT-L	Fuel Ullage Tank		0 to 5	x					
PFVC	Fuel Repressurization at Customer Connect Panel		0 to 2000	x					
PFVI	Fuel Repressurization Nozzle Inlet	KHP1	0 to 2000	x					
PFVL	Fuel Repressurization Nozzle Throat	KHP2	0 to 1000	x					
PHET-1P	Helium Tank	HN1-1	0 to 5000	x					x
PHET-2P	Helium Tank	HN1-2	0 to 5000	x					
PHET-3P	Helium Tank	HN1-3	0 to 5000	x					
PHPS-1P	Pneumatic System	HN4	0 to 750	x					
PHODP-1	Oxidizer Dome Purge at Customer Connect Panel		0 to 750	x					
POIML	Oxidizer Idle-Mode Line	PO10	0 to 2000		x				
POIML-L	Oxidizer Idle-Mode Line	PO10	0 to 50		x				
POJ-1	Oxidizer Injection	CO3	0 to 1500	x					
POJ-2	Oxidizer Injection	CO3e	0 to 1500	x		x			
POJ-2L	Oxidizer Injection	CO3e	0 to 50	x		x			
POJ-3	Oxidizer Injection Manifold	COIb	0 to 2000		x				
POPBC	Oxidizer Pump Bearing Coolant	PO7	0 to 500	x					
POPO-1L	Oxidizer Pump Discharge	POI	0 to 50	x					
POPO-1P	Oxidizer Pump Discharge	PO3	0 to 2500	x					
POPO-2	Oxidizer Pump Discharge * †	PO2	0 to 3500	x	x	x			
POPI-1	Oxidizer Pump Inlet	PO1	0 to 100	x					x
POPI-2	Oxidizer Pump Inlet		0 to 100	x					x
POPI-3	Oxidizer Pump Inlet	PO1e	0 to 100	x	x	x			
POPSC	Oxidizer Pump Primary Seal Cavity	PO6	0 to 50	x					
PORPO	Oxidizer Recirculation Pump Outlet * † ††		0 to 100	x					
PORPR	Oxidizer Recirculation Pump Return * † ††		0 to 100	x					
POTI-1P	Oxidizer Turbine Inlet	TG3	0 to 200	x					
POTO-1P	Oxidizer Turbine Outlet	TG4	0 to 100	x					
POUT	Oxidizer Ullage Tank		0 to 100	x					
PPTD	Photocon Cooling Water (Downstream)		0 to 100	x					
PPTU	Photocon Cooling Water (Upstream)		0 to 100	x					

TABLE III-1 (Continued)

AEDC Code	Parameter	Tap Number	Range	Digital Data System	Magnetic Tape	Oscillo-graph	Strip Chart	Event Recorder	X-Y Plotter
	Pressure, psia								
PTCFJP	Thrust Chamber Fuel Jacket Purge		0 to 200	x					
	Speeds, rpm								
NFP-1	Fuel Pump	PFV	0 to 33000		x	x	x**		
NFP-2	Fuel Pump	PFV	0 to 33000	x					
NFP-3	Fuel Pump	PFV	0 to 33000			x			
NFRP	Fuel Recirculation Pump * † ††		0 to 15000	x					
NOP-1	Oxidizer Pump	POV	0 to 12000		x				
NOP-2	Oxidizer Pump	POV	0 to 12000	x					
NOP-3	Oxidizer Pump	POV	0 to 12000			x			
NORP	Oxidizer Recirculation Pump * † ††		0 to 15000	x					
	Temperatures, °F								
TA-1	Test Cell, North		-50 to 800	x					
TA-2	Test Cell, East		-50 to 800	x					
TA-3	Test Cell, South		-50 to 800	x					
TA-4	Test Cell, West		-50 to 800	x					
TECP-1P	Electrical Control Assembly	NST1a	-300 to 200	x					
TFASIJ	Augmented Spark Igniter Fuel Injection	IFT	-425 to 100	x		x			
TFD-Avg	Fire Detection		0 to 1000	x			x		
TFDFTA	Fire Detect Fuel Turbine Manifold Area		0 to 500	x					
TFDMFVA	Fire Detect Main Fuel Valve Area		0 to 500	x					
TFDMOVA	Fire Detect Main Oxidizer Valve Area		0 to 500	x					
TFDODA	Fire Detect Oxidizer Dome Area		0 to 500	x					
TFDTDA	Fire Detect Tapoff Duct Area		0 to 500	x					
TFJ-1P	Fuel Injection	CFT2	-425 to -300	x					
TFJ-2P	Fuel Injection	CFT2a	-425 to 100	x		x	x		
TFPBS	Fuel Pump Balance Piston Sump	PFT4	-425 to 100	x			x		
TFPD-1P	Fuel Pump Discharge	PFT1	-425 to -900	x	x				
TFPD-2P	Fuel Pump Discharge	PFT1	-425 to 100	x					
TFPI-1	Fuel Pump Inlet	KFT2	-425 to -400	x					x
TFPI-2	Fuel Pump Inlet	KFT2a	-425 to 100	x					x
TFRPO	Fuel Recirculation Pump Outlet * † ††		-425 to -350	x					
TFRPR	Fuel Recirculation Pump Return * † ††		-425 to -250	x					
TFRT-1	Fuel Run Tank		-425 to -400	x					
TFRT-3	Fuel Run Tank		-425 to -400	x					
TFTI-1P	Fuel Turbine Inlet	GGT3	-300 to 1800	x					
TFTI-4	Fuel Turbine Inlet		-300 to 2000	x					
TFVC	Fuel Repressurization at Customer Connect Panel		-300 to -100	x					
TFVL	Fuel Repressurization Nozzle Inlet	KHPT1	-300 to -100	x					
THET-1P	Helium Tank	NNT1	-200 to 300	x					x
THETA-1	Helium Tank Area -1		0 to 500	x					
THETA-2	Helium Tank Area -2		0 to 500	x					
TLCS-E	Load Cell Surface East		-240 to 300	x					
TLCS-N	Load Cell Surface North		-240 to 300	x					
TMOVF	Main Oxidizer Valve Flange * †††		-300 to 100	x		x	x		

TABLE III-1 (Continued)

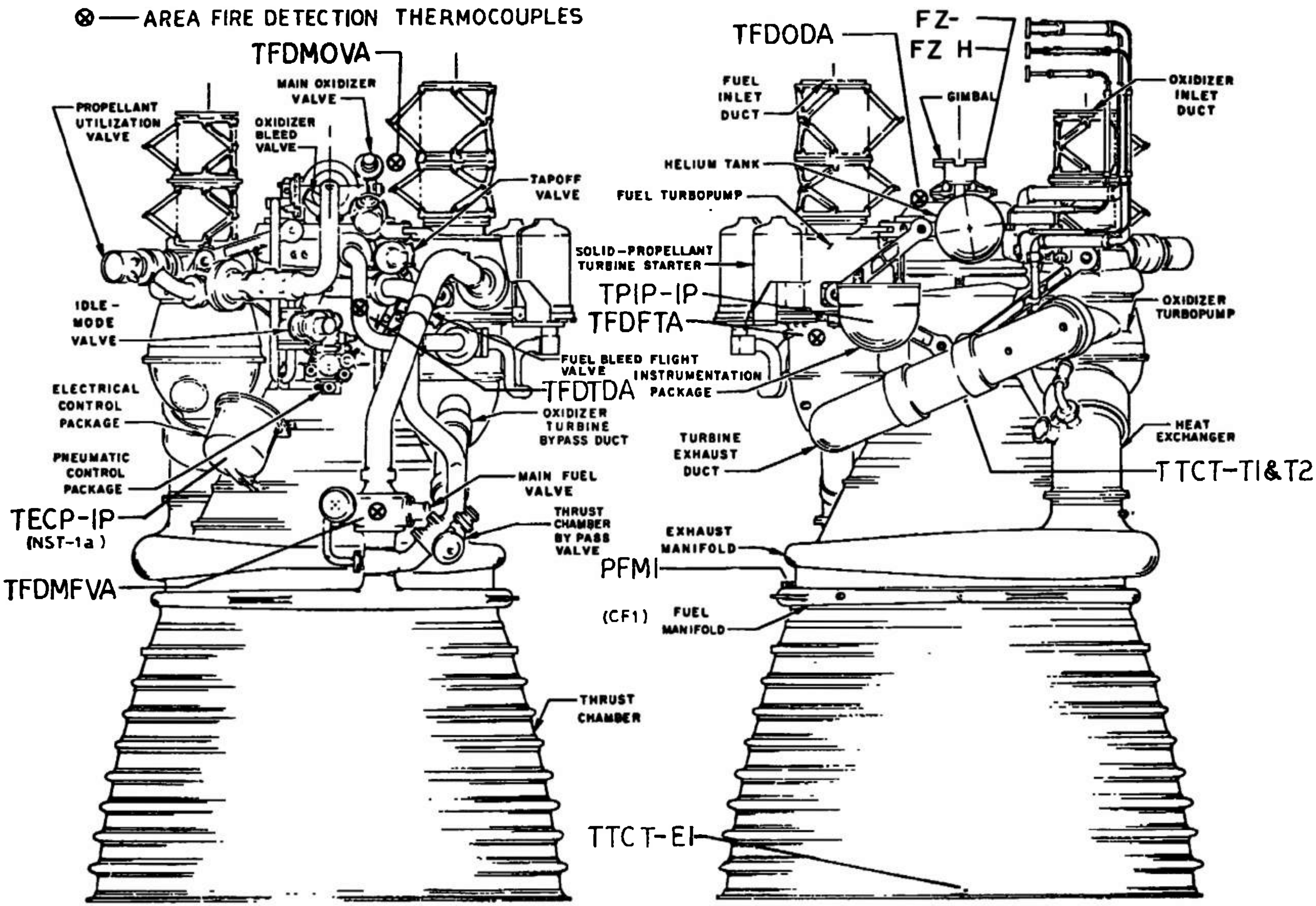
AEDC Code	Parameter	Tap Number	Range	Digital Data System	Magnetic Tape	Oscillo-graph	Strip Chart	Event Recorder	X-Y Plotter
	Temperature, °F								
TNOOP-1	Oxidizer Dome Purge at Customer Connect Panel		-250 to 200	x					
TOIML	Oxidizer Idle Mode Line	POT5	-300 to 100	x					
TOJ	Oxidizer Injection	COT1	-300 to 1200	x		x	x		
TOPBC	Oxidizer Pump Bearing Coolant	POT4	-300 to 1950	x			x		
TOPD-1P	Oxidizer Pump Discharge	POT3	-300 to -250	x					
TOPD-2P	Oxidizer Pump Discharge	POT3	-300 to 100	x					
TOPI-1	Oxidizer Pump Inlet	KOT2	-310 to -250	x					x
TOPI-2	Oxidizer Pump Inlet	KOT2a	-310 to 100	x					x
TORPO	Oxidizer Recirculation Pump Outlet * † ††		-300 to -250	x					
TORPR	Oxidizer Recirculation Pump Return * † ††		-300 to -140	x					
TORT-1	Oxidizer Run Tank		-300 to -285	x					
TORT-3	Oxidizer Run Tank		-300 to -285	x					
TOTI-1P	Oxidizer Turbine Inlet	TGT2	0 to 1200	x					
TOTO-1P	Oxidizer Turbine Outlet	TGT4	0 to 1000	x					
TPIP-1P	Instrumentation Package		-300 to 200	x					
TPTU	Photocon Cooling Water (Upstream)		0 to 300	x					
TSCGA-1	Solid-Propellant Turbine Starter Cond. Gas 1 *		-100 to 300	x					
TSCGA-2	Solid-Propellant Turbine Starter Cond. Gas 2 *		-100 to 300	x					
TSCGA-3	Solid-Propellant Turbine Starter Cond. Gas 3 *		-100 to 300	x					
TTCP	Thrust Chamber Purge		-250 to 200	x					
TTCT-T1	Thrust Chamber Tube (Exit)		-425 to 500	x					
TTCT-T1	Thrust Chamber Tube (Throat)		-425 to 500	x			x **		
TTCT-T2	Thrust Chamber Tube (Throat)		-425 to 500	x					
TTMS-1	Tapoff Valve †		0 to 2000	x		x	x		
TTMS-2	Tapoff Valve *		0 to 2000	x		x	x		
	Peak Vibrations, g								
UFPR	Fuel Pump Radial		450 peak		x				
UFTR	Fuel Turbine Radial *		450 peak		x				
UOPR	Oxidizer Pump Radial	PZA-2	300 peak		x				
UTCD-1	Thrust Chamber Dome	PZA-1a	1400 peak		x	x			
UTCD-2	Thrust Chamber Dome	PZA-2	1400 peak		x	x			
UTCD-3	Thrust Chamber Dome	PZA-3	300 peak		x	x			
	Voltage, volts								
VCB	Control Bus		0 to 36	x					
VIB	Ignition Bus		0 to 36	x					
VIDA-1	Ignition Detect Amplifier		9 to 16	x					
VIDA-2	Ignition Detect Amplifier		9 to 16	x					
VPUVEP	Propellant Utilization Valve Telemetry Potentiometer Excitation		0 to 5	x					

NOTES:

- * Not required for J4-1001-16
- ** Added pretest J4-1001-17
- † Not required for J4-1001-17
- †† Not required for J4-1001-18
- *** Required for tests J4-1001-16 and 17 only
- ††† Not required for J4-1001-19

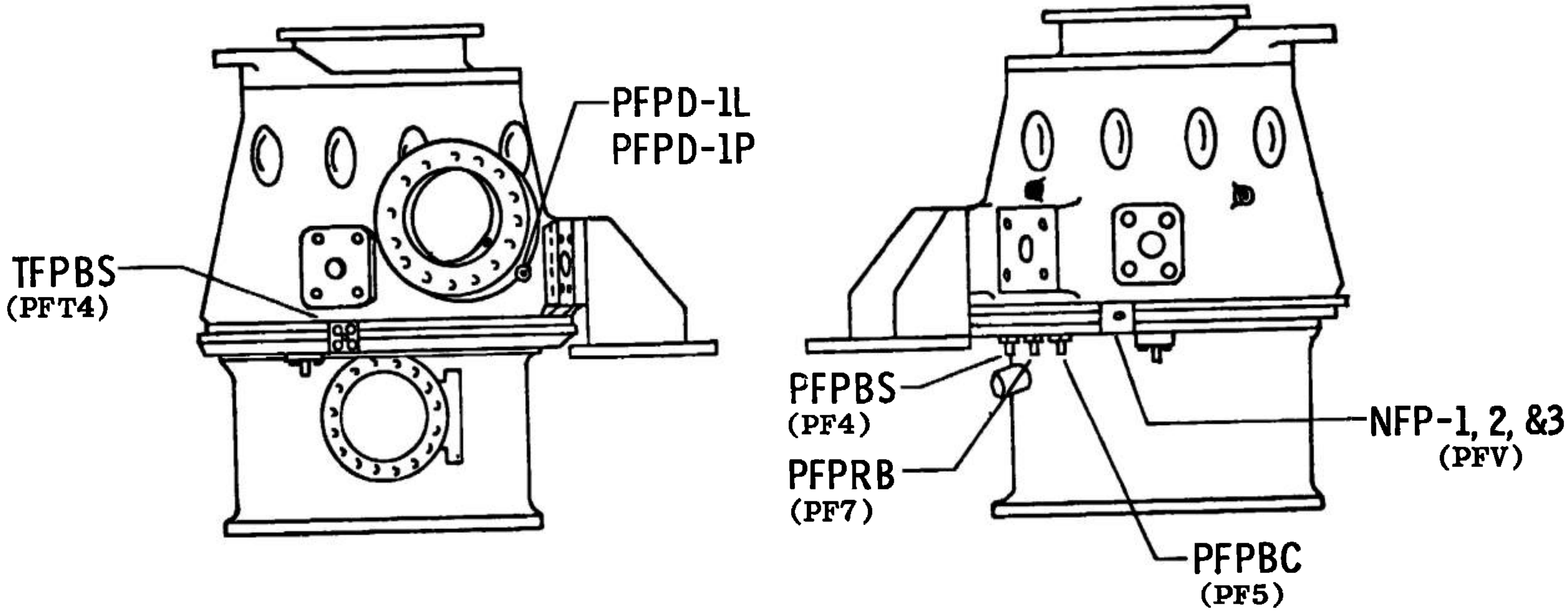
TABLE III-1 (Concluded)

AEDC Code	Parameter	Tap Number	Range	Digital Data System	Magnetic Tape	Oscillo-graph	Strip Chart	Event Recorder	X-Y Plotter
	Current, amp								
ICC	Control		0 to 30	x					
IIC	Ignition		0 to 30	x					
	Event								
EASIS-1	Augmented Spark Igniter Spark -1		On/Off					x	
EASIS-2	Augmented Spark Igniter Spark -2		On/Off					x	
EECL	Engine Cutoff Lockin		On/Off	x		x		x	
EECO	Engine Cutoff Signal		On/Off	x		x		x	
EER	Engine Ready Signal		On/Off					x	
EES	Engine Start Command		On/Off	x		x		x	
EEBCO	Programmed Duration Cutoff		On/Off					x	
EFPCO	Fuel Pump Overspeed Cutoff		On/Off					x	
EFPVC	Fuel Prevalve Closed Limit		On/Off	x				x	
EFPVO	Fuel Prevalve Open Limit		On/Off	x				x	
EFS	Fire Switch *†		On/Off	x					
EFUA	Exploding Bridgewire Firing Units Armed		On/Off					x	
EHCS	Helium Control Solenoid Energized		On/Off	x	x	x		x	
EHGTC	Hot Gas Tapoff Valve Closed Limit		On/Off					x	
EHGTO	Hot Gas Tapoff Valve Open Limit		On/Off					x	
EID	Ignition Detected		On/Off	x		x		x	
EIDA-1	Ignition Detect Amplifier -1		On/Off					x	
EIDA-2	Ignition Detect Amplifier -2		On/Off					x	
EIMCS	Idle-Mode Control Solenoid Energized		On/Off	x		x		x	
EIMVC	Idle-Mode Valve Closed Limit		On/Off					x	
EIMVO	Idle-Mode Valve Open Limit		On/Off					x	
EMCL	Main-Stage Cutoff Lockin		On/Off	x		x		x	
EMCO	Main-Stage Cutoff Signal		On/Off	x		x			
EMCS	Main-Stage Control Solenoid Energized		On/Off	x		x		x	
EMD-1	Main-Stage "OK" Depressurized -1		On/Off	x		x		x	
EMD-2	Main-Stage "OK" Depressurized -2		On/Off	x		x		x	
EMFVC	Main Fuel Valve Closed Limit		On/Off					x	
EMFVO	Main Fuel Valve Open Limit		On/Off					x	
EMOVC	Main Oxidizer Valve Closed Limit		On/Off					x	
EMOVO	Main Oxidizer Valve Open Limit		On/Off					x	
EMP-1	Main-Stage "OK" Pressurized -1		On/Off	x		x		x	
EMP-2	Main-Stage "OK" Pressurized -2		On/Off	x				x	
EMPCO	Main-Stage Pressure Cutoff Signal		On/Off					x	
EMS	Main-Stage Start Signal		On/Off					x	
EMSCO	Main-Stage Programmed Duration Cutoff		On/Off					x	
EMSS	Main-Stage Start Solenoid Energized		On/Off	x	x	x		x	

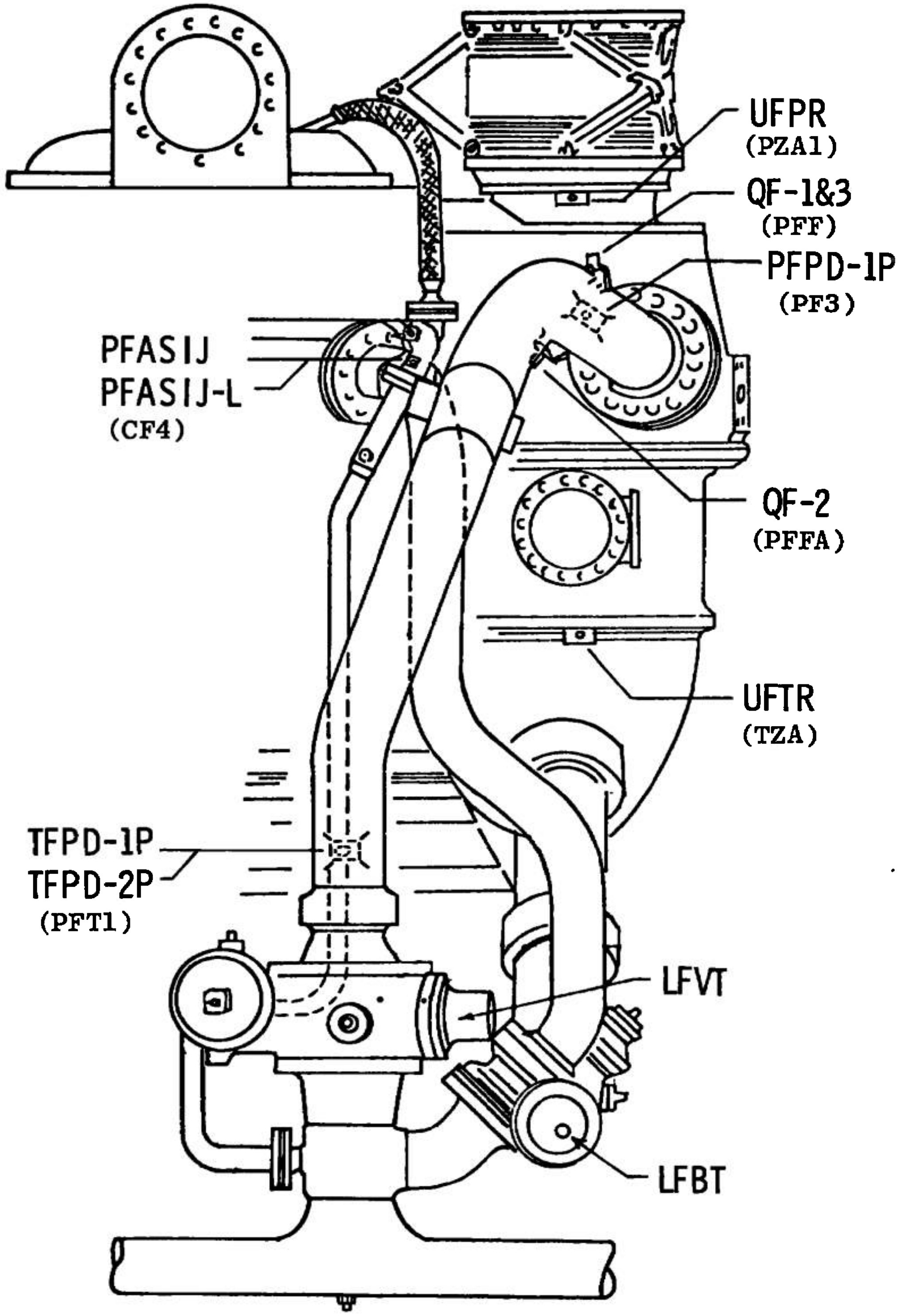


a. General Arrangement

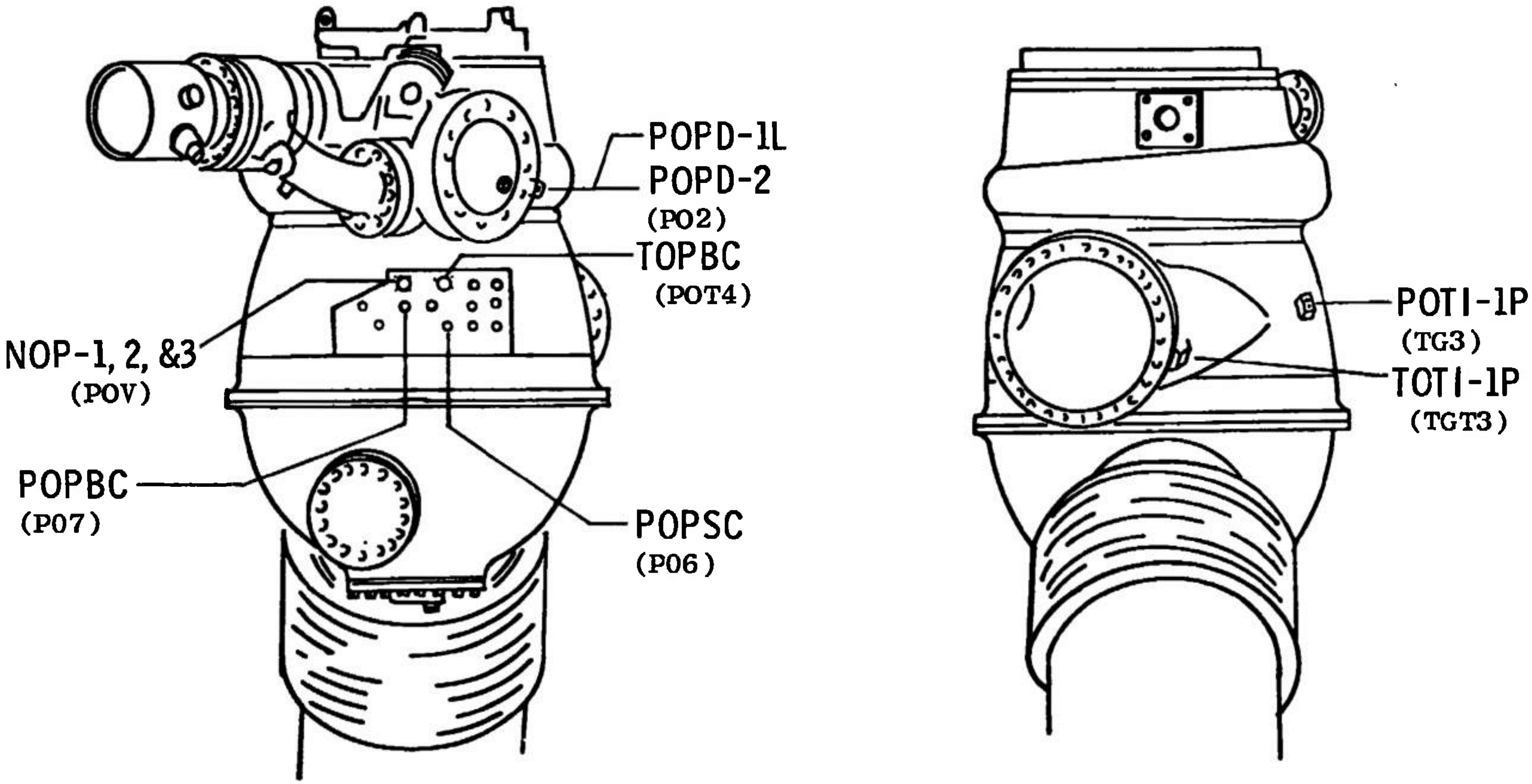
Fig. III-1 Selected Sensor Locations



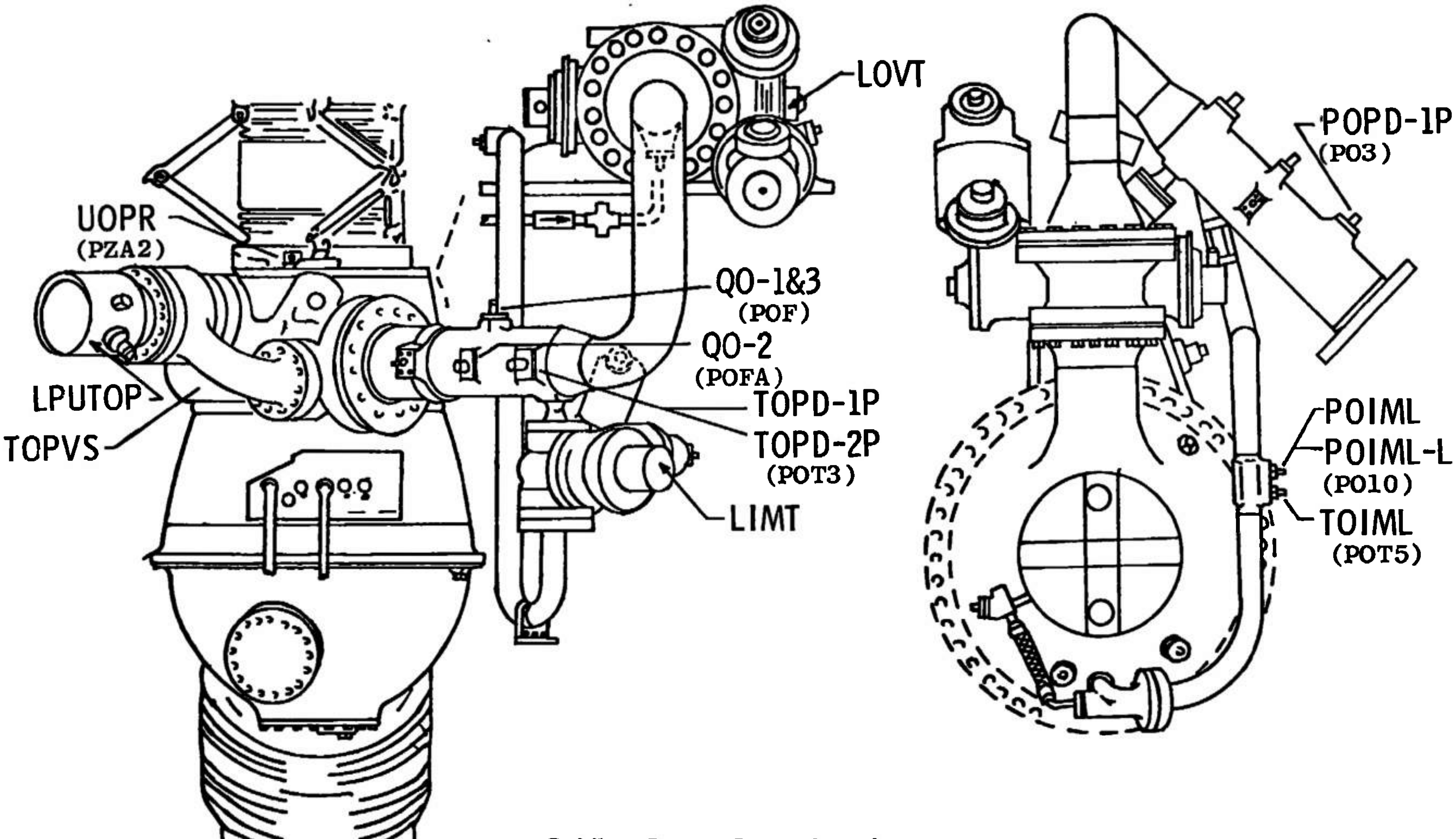
b. Fuel Turbopump Sensor Locations
Fig. III-1 Continued



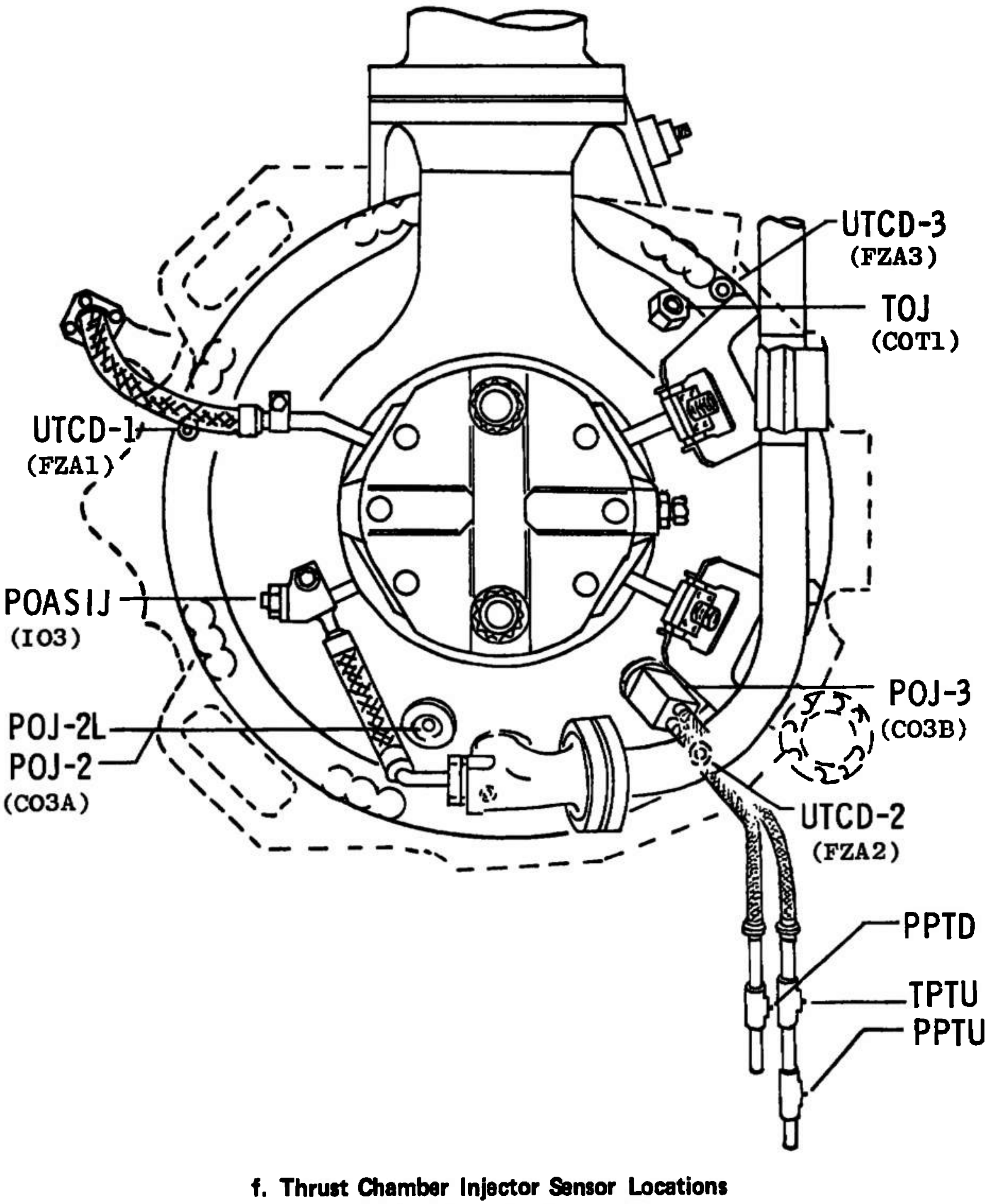
c. Fuel System Sensor Locations
Fig. III-1 Continued



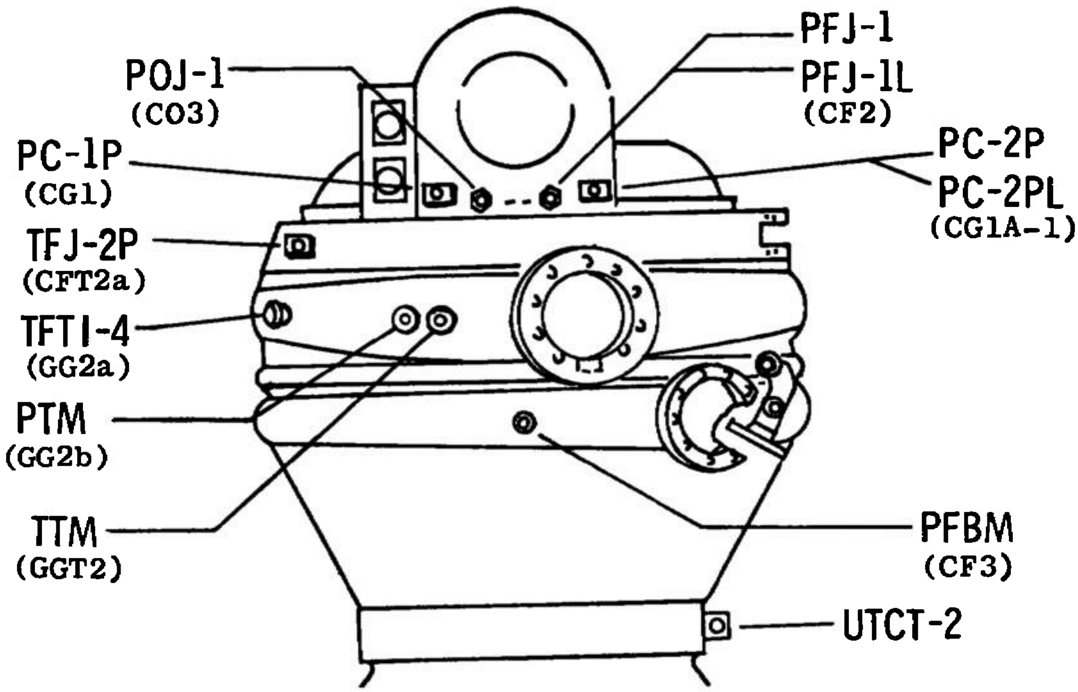
d. Oxidizer Turbopump Sensor Locations
Fig. III-1 Continued

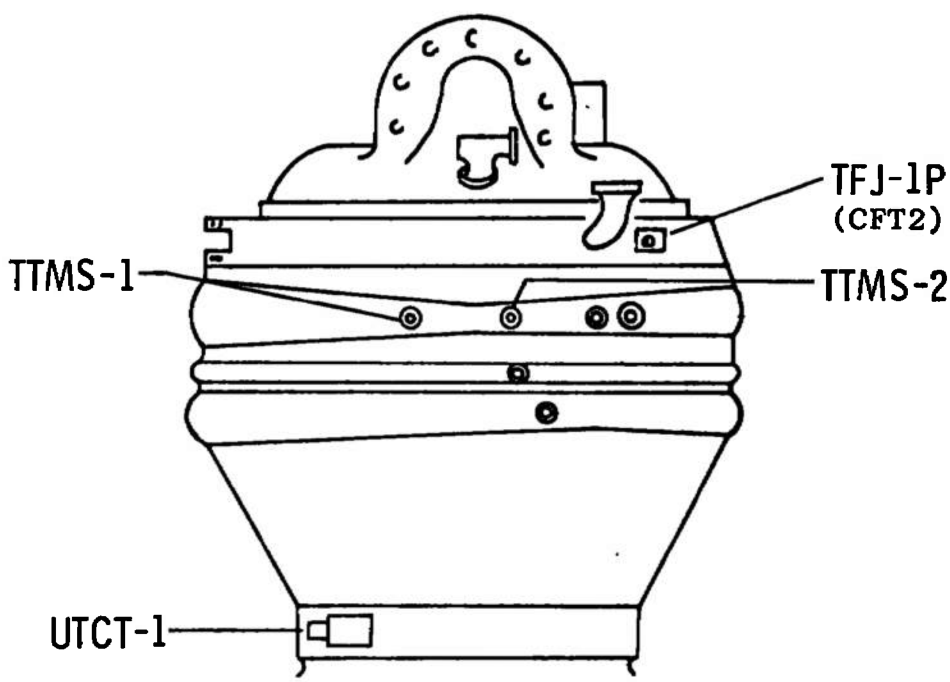


e. Oxidizer System Sensor Locations
Fig. III-1 Continued

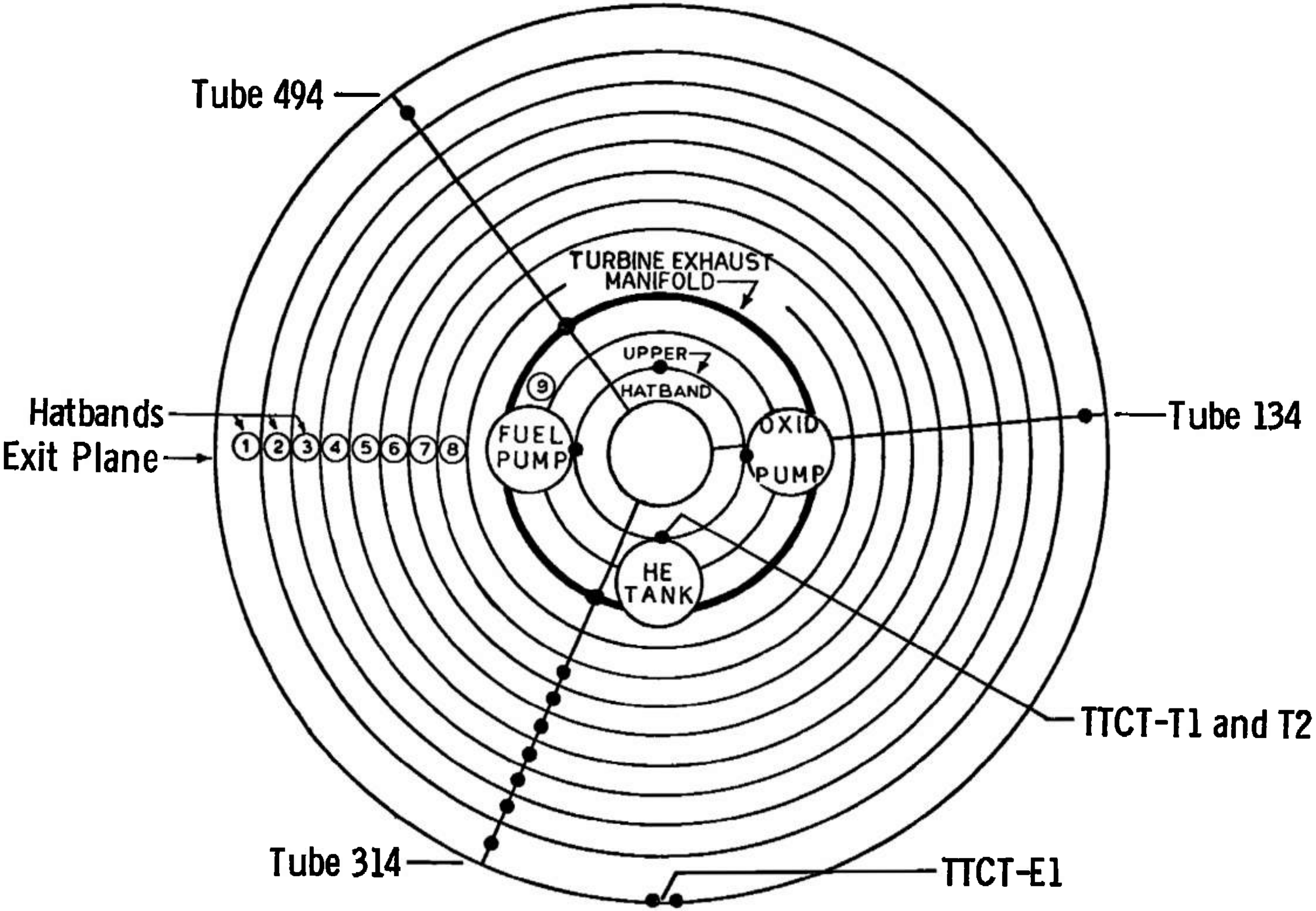


f. Thrust Chamber Injector Sensor Locations
Fig. III-1 Continued



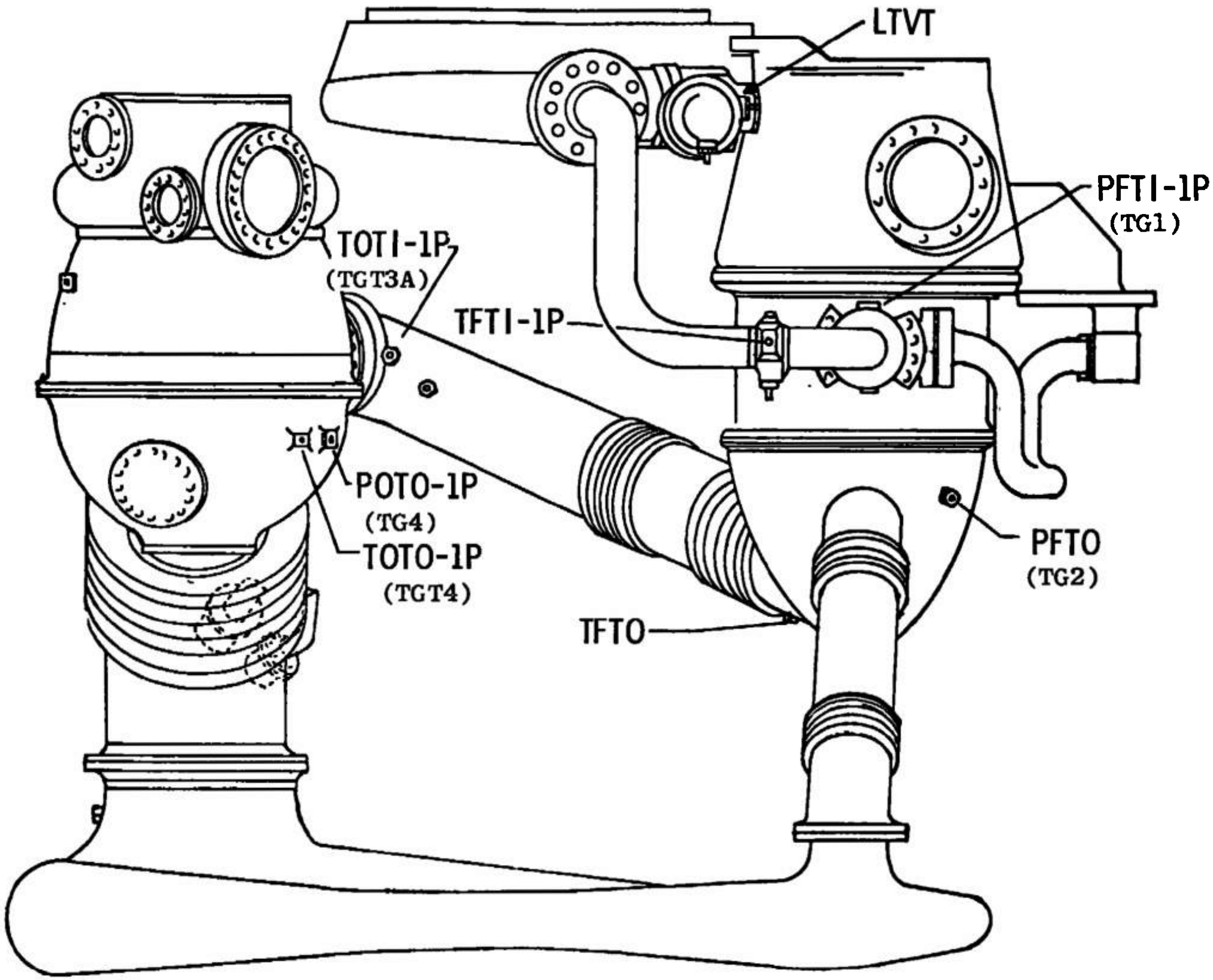


g. Thrust Chamber Sensor Locations
Fig. III-1 Continued

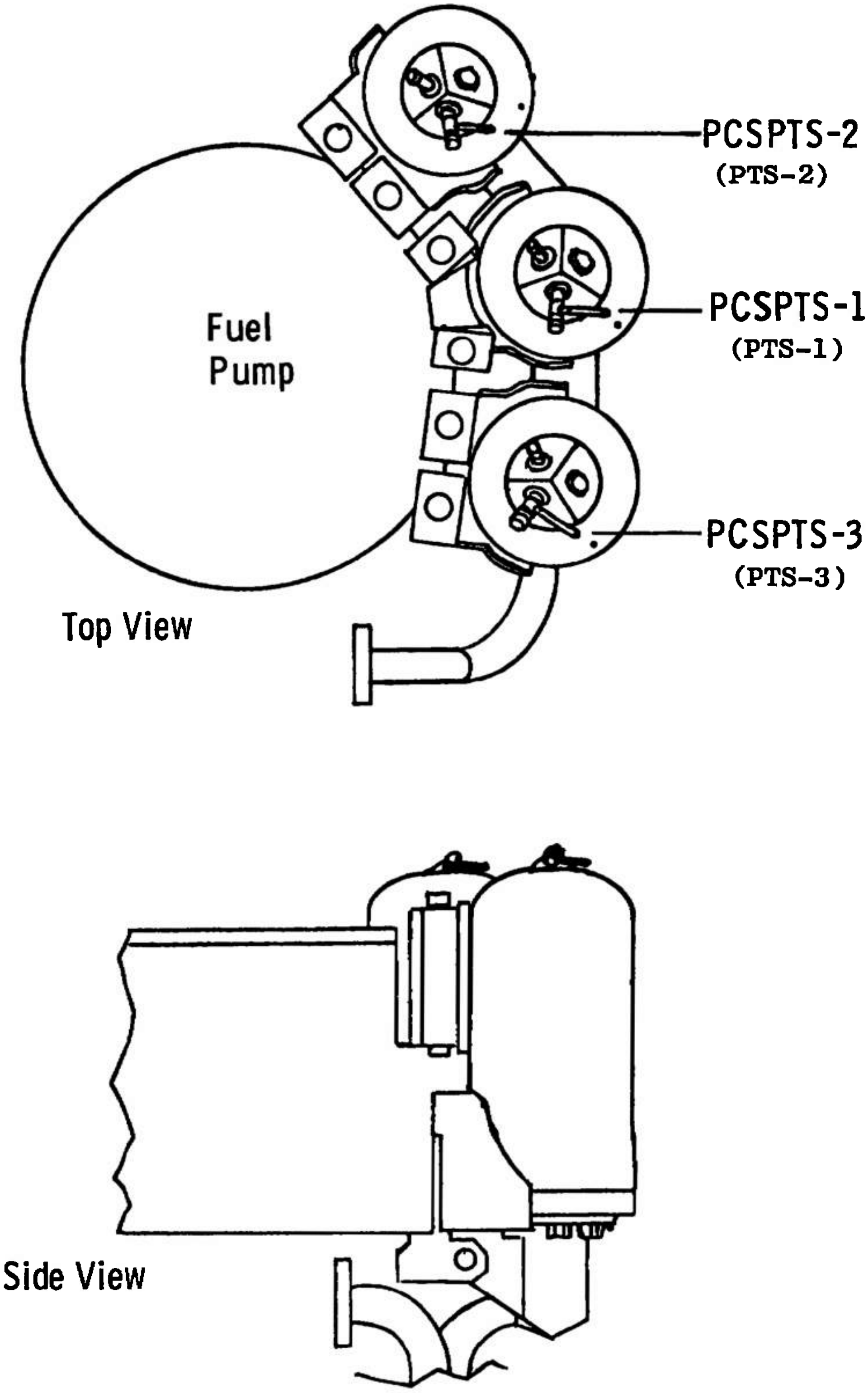


View Looking Downstream

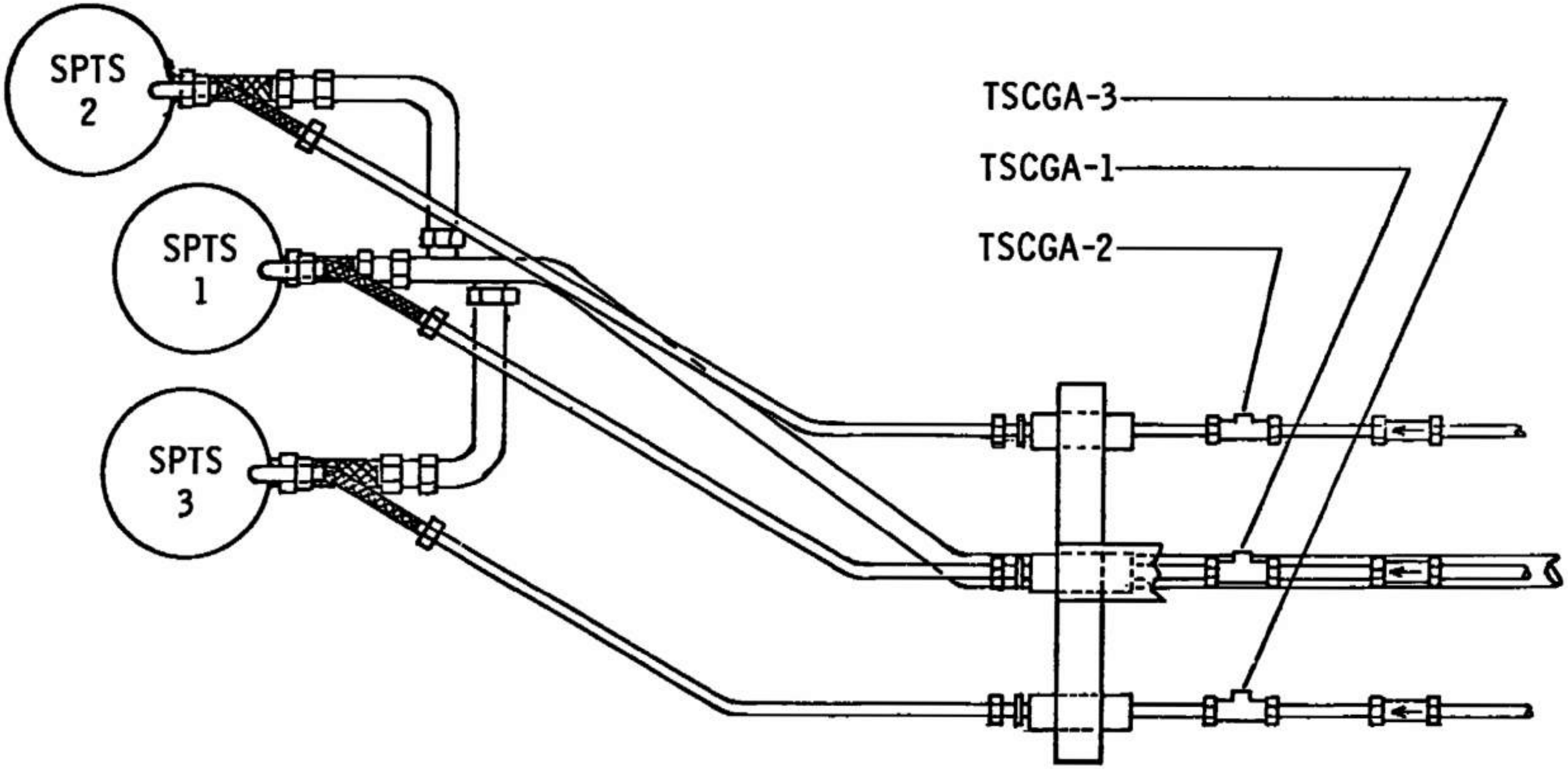
h. Thrust Chamber Sensor Locations
Fig. III-1 Continued



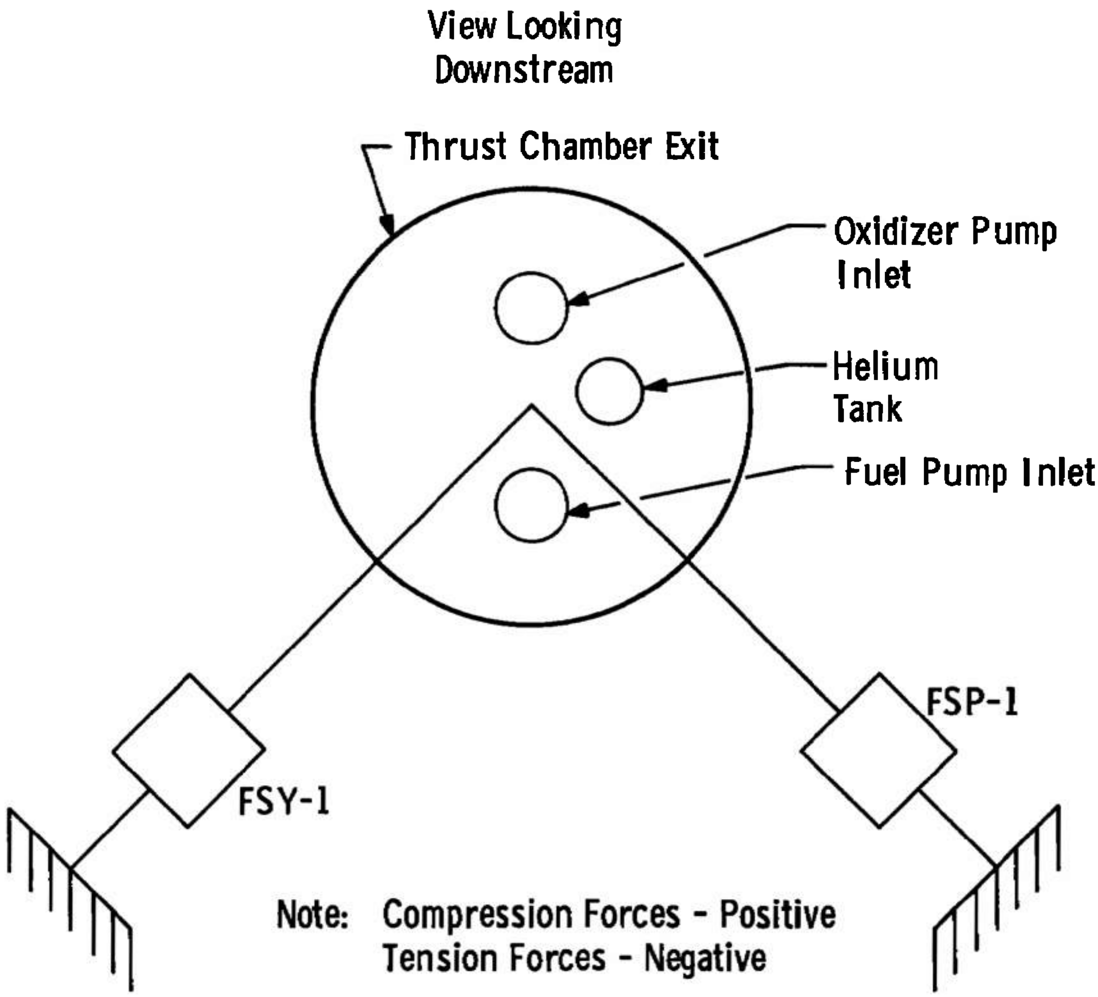
i. Turbine Exhaust Systems Sensor Locations
Fig. III-1 Continued



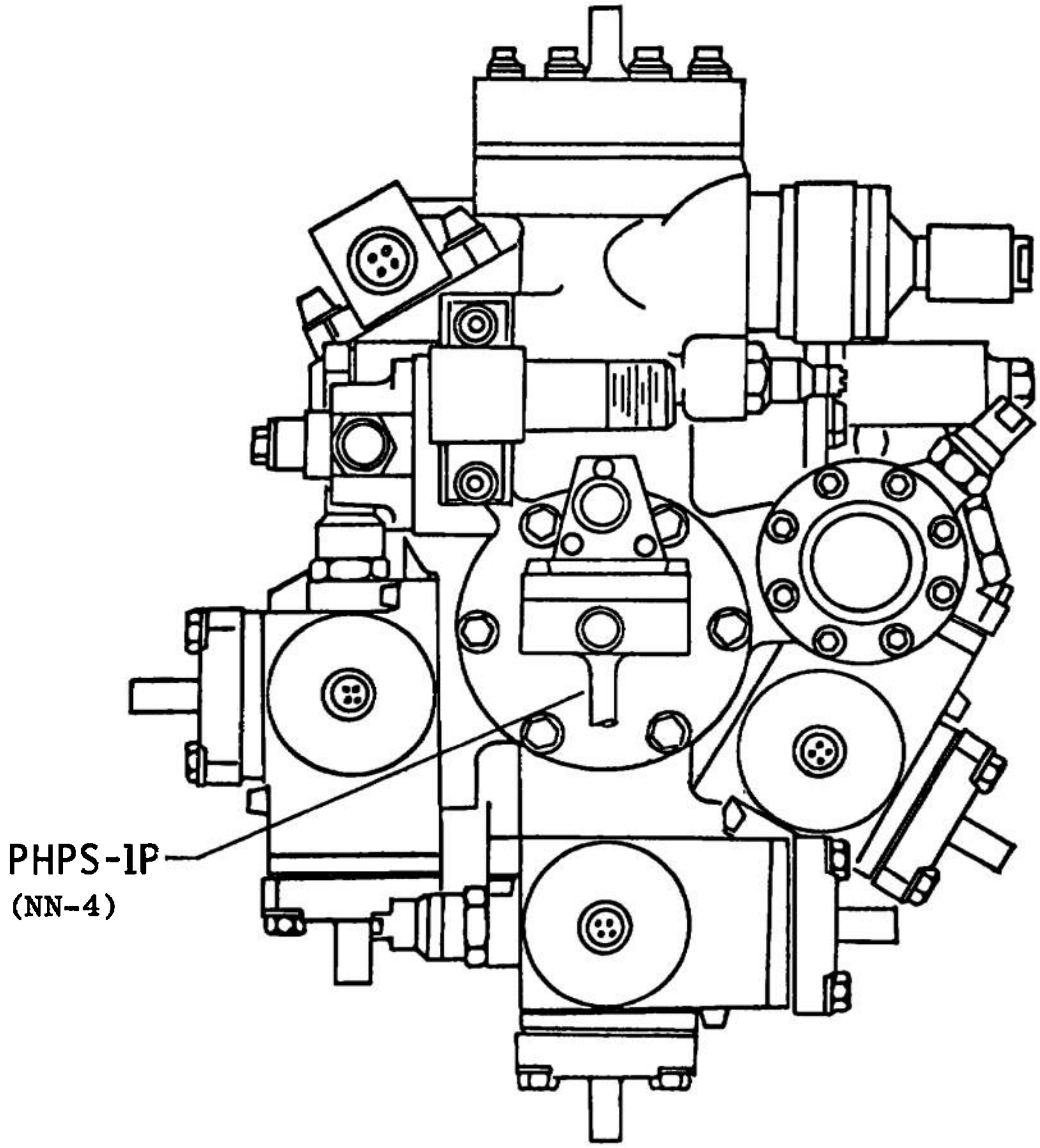
j. Solid-Propellant Turbine Starter Sensor Locations
Fig. III-1 Continued



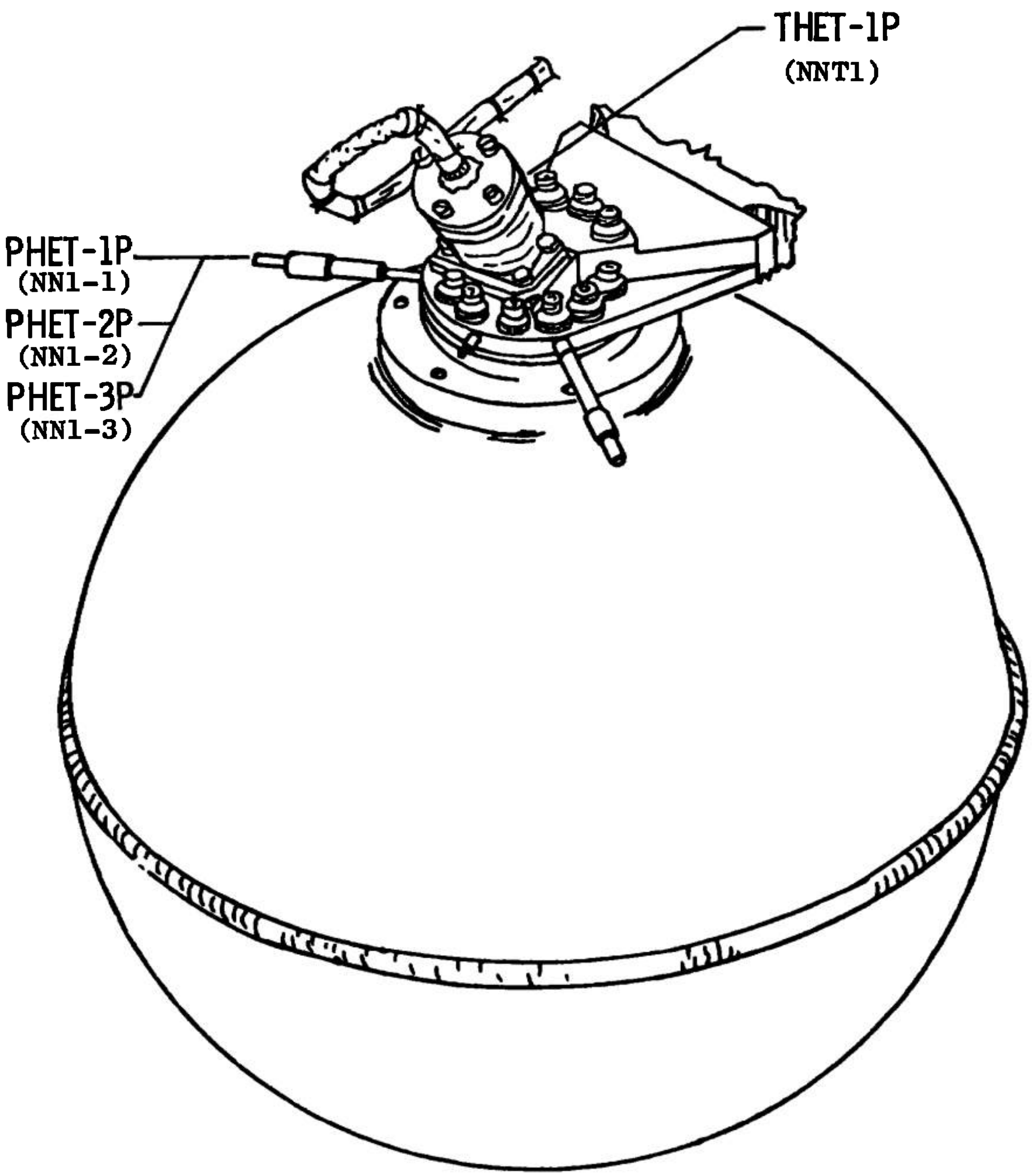
k. Solid-Propellant Turbine Starter Conditioning System Sensor Locations
Fig. III-1 Continued



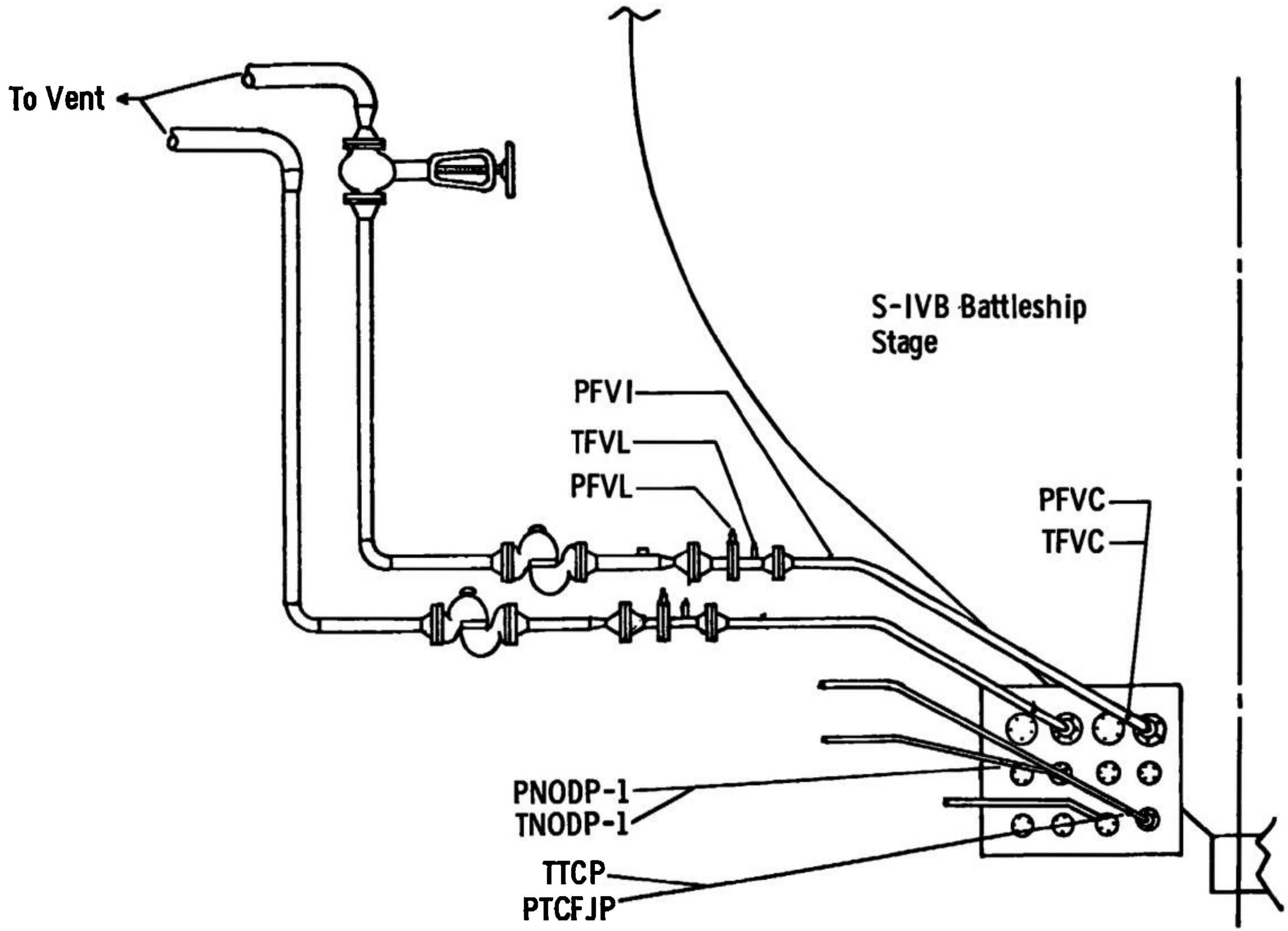
I. Side Load Forces Sensor Locations
Fig. III-1 Continued



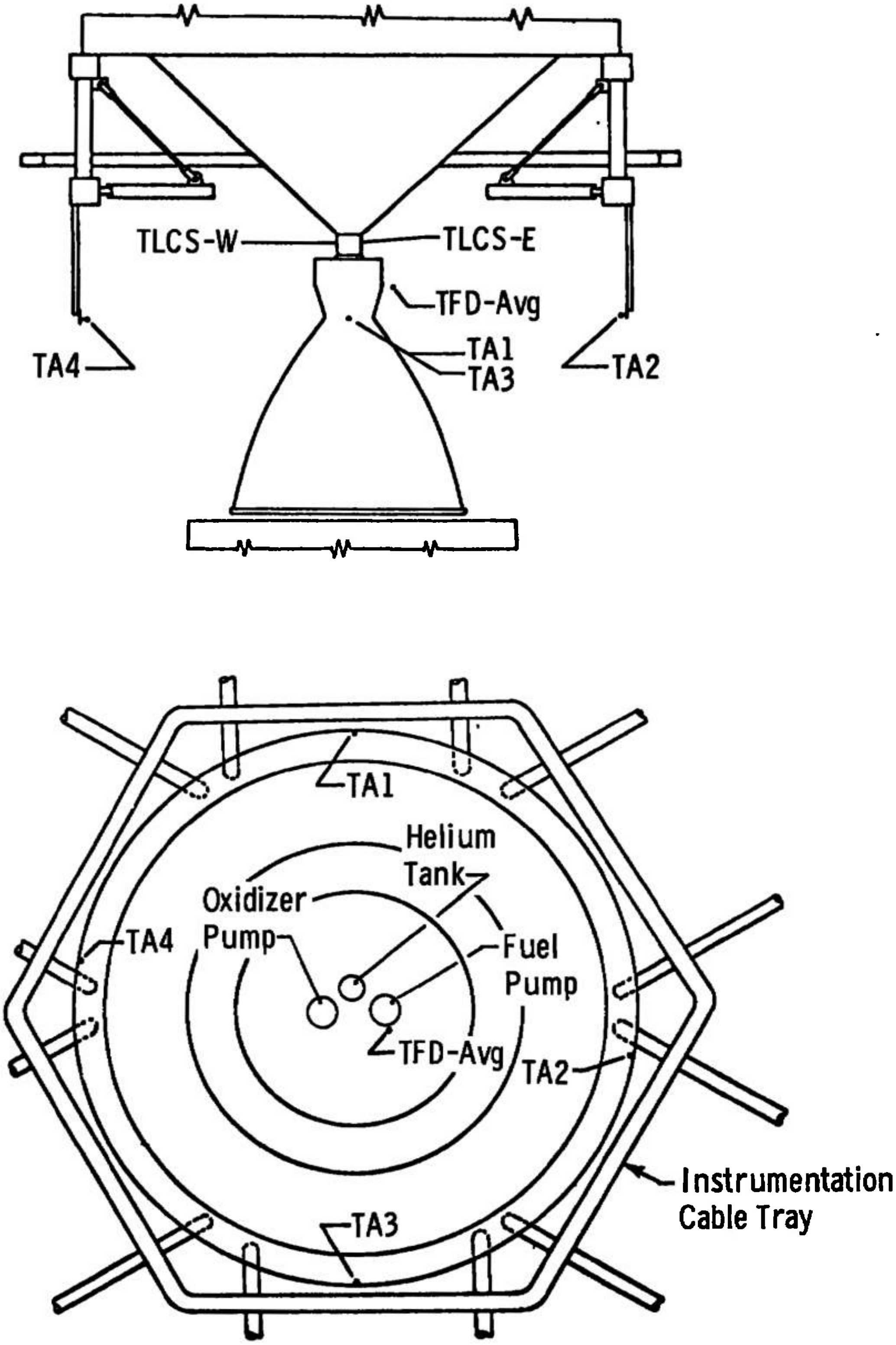
m. Pneumatic Control Package Sensor Locations
Fig. III-1 Continued



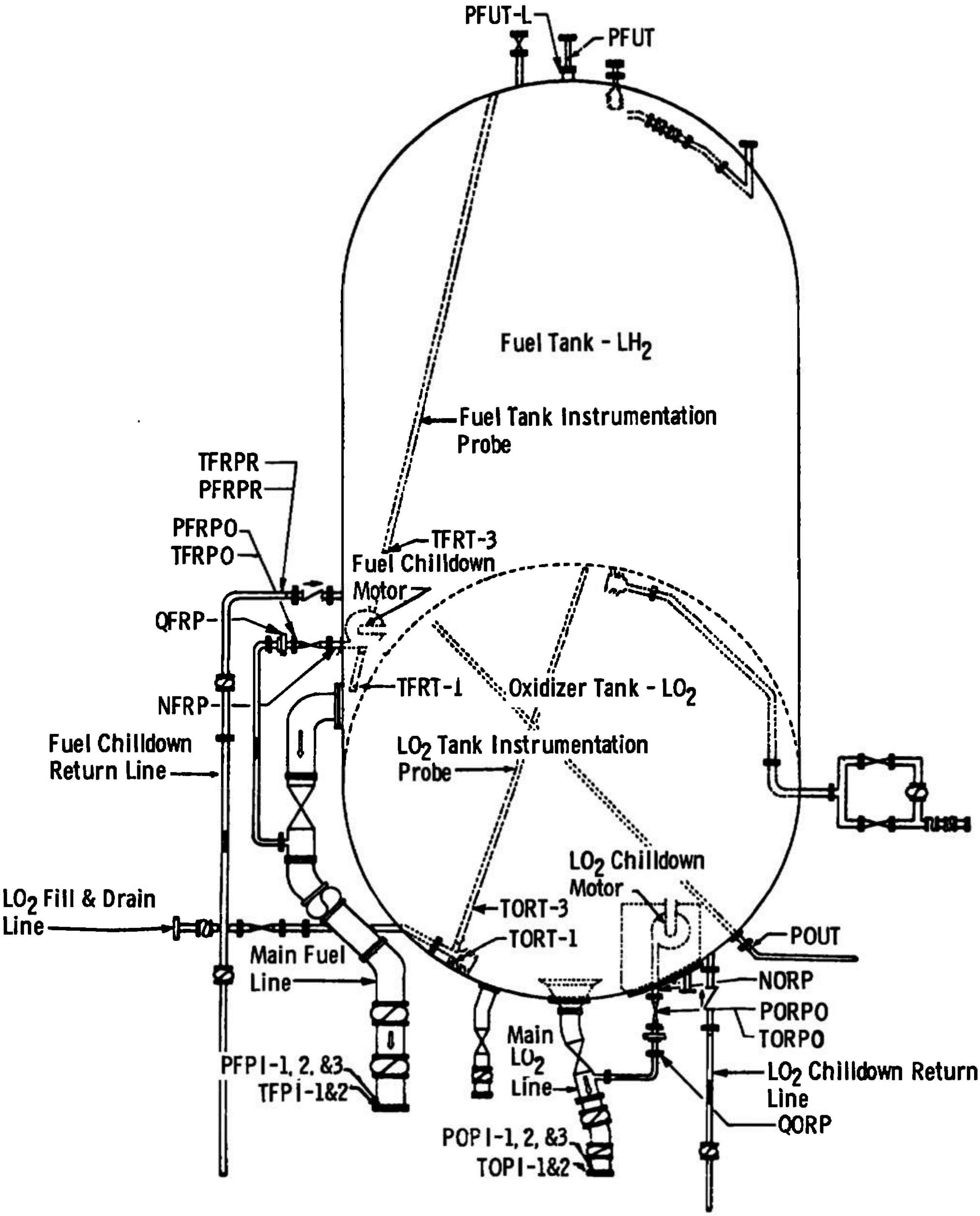
n. Helium Tank Sensor Locations
Fig. III-1 Continued



o. Customer Connect Panel Sensor Locations
Fig. III-1 Continued



p. Test Cell Ambient Temperature Sensor Locations
Fig. III-1 Continued



q. S-IVB Battleship Sensor Locations
Fig. III-1 Concluded

APPENDIX IV
FIRING SUMMARY

Firing J4-1001-16A

Firing 16A was an 81.5-sec idle-mode firing. The objective of this firing was to determine engine operating characteristics at various pump inlet pressures; of particular interest was operation at the higher oxidizer/fuel mixture ratios. The scheduled 200-sec firing was terminated prematurely because of thrust chamber external throat temperatures in excess of existing redline limits (200°F). The oxidizer idle-mode line orifice size was reduced for subsequent test periods.

Firing J4-1001-17A

Firing 17A was a 1.0/59.7-sec idle-mode/main-stage throttle firing. The objective of this firing was to determine engine operating characteristics at throttled conditions (utilizing a variable position hot gas tapoff valve) with an open propellant utilization valve. The firing was conducted for programmed duration. All engine parameters indicated highly satisfactory operating characteristics.

Firing J4-1001-17B

Firing 17B was a 1.0/60.0-sec idle-mode/main-stage throttle firing. The objective of this firing was to determine engine operating characteristics with a null propellant utilization valve. Little steady-state data were obtained at throttled conditions because of problems experienced by the tapoff valve control operator in setting specified condition. Apparently, hydraulic fluid used for tapoff valve stop control became chilled, affecting system response. Engine response was excellent, however, to all changes in tapoff valve position changes.

Firing J4-1001-17C

Firing 17C was scheduled to be a throttle firing, but was later changed to an idle-mode test in the control room after the tapoff valve would not respond to commands (this was later attributed to hydraulic fluid in the control system being chilled below fluid pour point (-30°F); this was resolved for subsequent tests by shielding the hydraulic supply line from cold gases used to condition engine components). Objectives of the idle-mode firing were identical to those of firing 16A, but with a reduced size oxidizer idle-mode line orifice. The initial 40 sec of operation was successfully conducted at conditions that resulted in premature termination during 16A. The firing was terminated prematurely, however, after 69.6 sec, when inadvertent operation of a facility component caused hot exhaust gas to recirculate into the test cell, resulting in excessive thrust chamber temperatures.

Firing J4-1001-18A

Firing 18A was a 1.0/60.1-sec idle-mode/main-stage throttle firing with a closed propellant utilization valve. The objective was to further evaluate engine operating

characteristics, especialy fuel pump performance, after throttling to within a 200- to 500-gpm margin from the fuel pump 65-percent efficiency maximum head line. All objectives were met; engine operation was satisfactory.

Firing J4-1001-18B

Firing 18B was a 1.0/60.2-sec idle-mode/main-stage throttle firing with a null propellant utilization valve. Objectives were identical to those of 18A, except for propellant utilization valve position. Objectives were met; engine operation was satisfactory.

Firing J4-1001-19A

Firing 19A was a 1.0/2.0-sec idle-mode/main-stage transition firing. The objectives of this firing (a scheduled 35-sec firing) were to further document engine throttled operation as well as to evaluate engine transient operation after propellant conditioning and prechilling the engine pumps with the S-IVB stage propellant recirculation system. Premature termination occurred when the augmented spark igniter ignition detect signal was not initiated as required by facility logic; test objectives were not attained. The recirculation pumps did not function properly and were not used as planned. Bleed valve installation apparently reduced transient oxidizer/fuel mixture ratio in the augmented spark igniter chamber and lowered combustion temperature (ignition is indicated by a heat-sensitive element in the augmented spark igniter chamber).

Firing J4-1001-19B

Firing 19B was a 202.4-sec idle-mode firing. The objective was to demonstrate satisfactory engine operation at several combinations of fuel/oxidizer pump inlet pressure conditions. Engine operation was completely satisfactory with no excessive thrust chamber throat temperature at the higher oxidizer/fuel mixture ratios.

Firing J4-1001-19C

Firing 19C was a 6.9/28.1-sec idle-mode/main-stage throttle firing. Objectives were identical to firing 19A which was not satisfactorily completed. The engine was throttled to within 200- to 500-gpm margin of the 65-percent efficiency maximum head line; propellant utilization valve was in the open position. The firing was automatically terminated about 5 sec early when fuel flow approached 2500 gpm, as indicated by the Rocketdyne-supplied stall approach monitor. The 2500-gpm level was established as lower cutoff limit.

Firing J4-1001-20A

Firing 20A was a 1.0/29.5/11.1-sec idle-mode/main-stage/post-main-stage idle-mode firing. The objectives were to (1) evaluate the S-IVB stage recirculation system effectiveness in prefire temperature conditioning of propellants and pumps, (2) determine main-stage performance and evaluate post-main-stage idle-mode operation. The firing was

satisfactorily completed as programmed. The S-IVB stage recirculation system was utilized effectively in conditioning propellants at the pump inlets. Main-stage performance was consistent with that realized on pretest 1001-16 main-stage firings.

Firing J4-1001-20B

Firing 20B was a scheduled main-stage throttle firing. However, the firing was prematurely terminated after 1.0 sec when the augmented spark igniter ignition detect signal was not initiated as required by facility logic. The firing was subsequently successfully conducted.

Firing J4-1001-20C

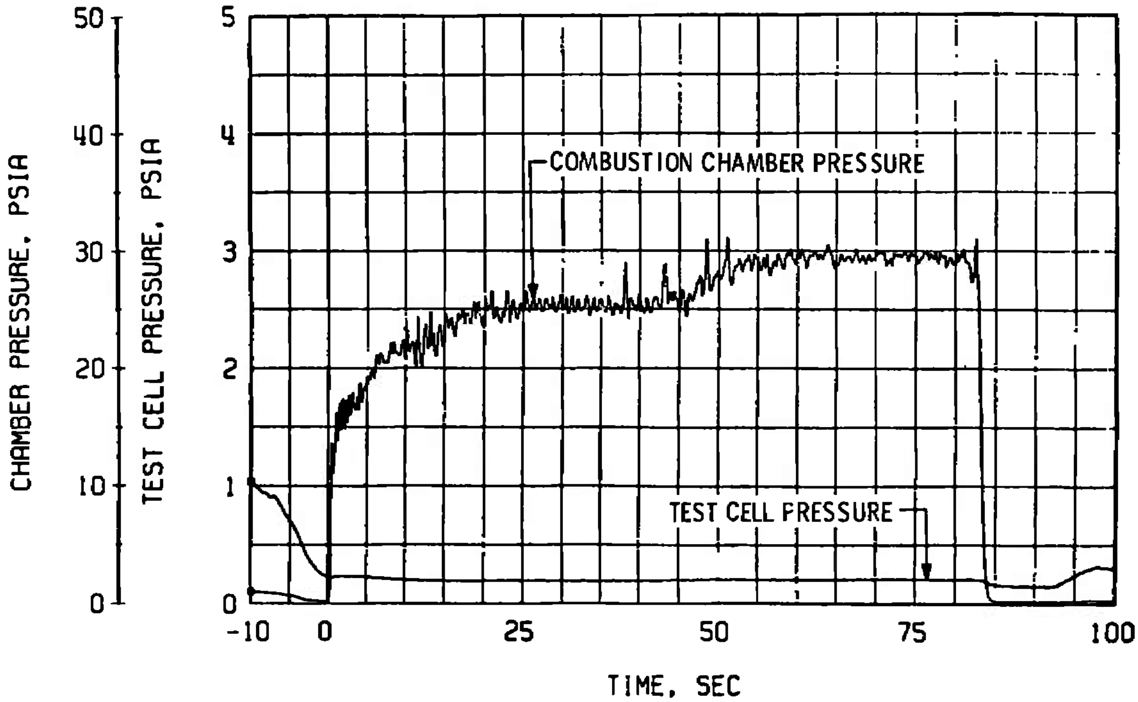
Firing 20C was a second attempt to conduct a main-stage throttle firing. However, after 9.2/3.2 sec of idle-mode/main-stage transition, the propellant utilization valve was inadvertently prematurely closed and the test terminated. Engine transition operation was satisfactory after prefire conditioning propellants with the S-IVB stage recirculation system.

Firing J4-1001-20D

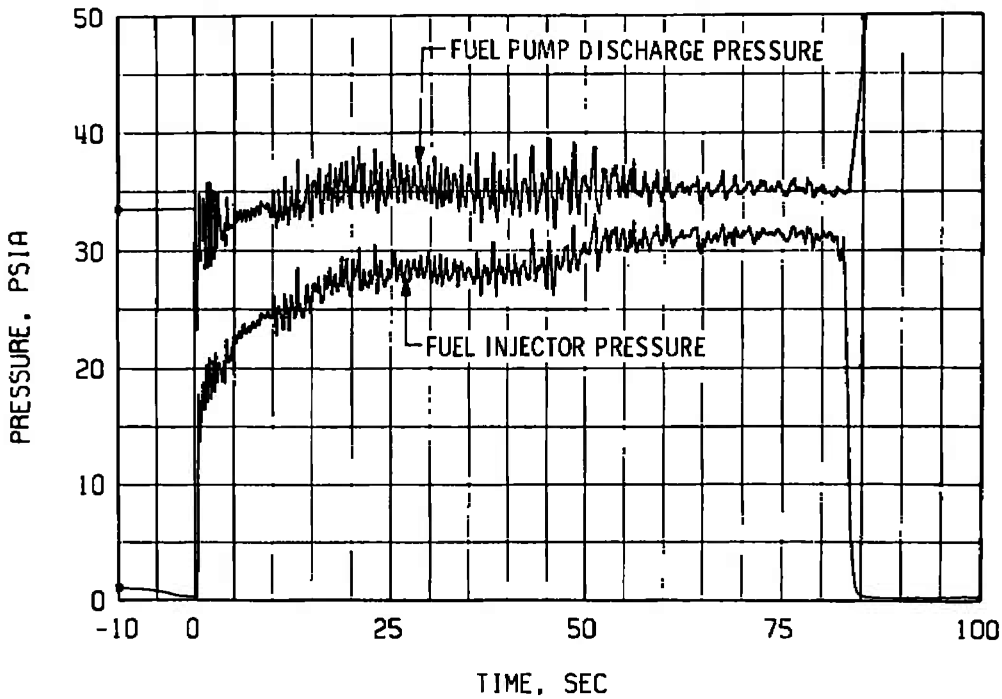
Firing 20D was a 6.3/50.5-sec idle-mode/main-stage throttle firing. The objective was to determine engine operating characteristics after throttling to a chamber pressure of 250 psia (minimum throttle setting of the test program) with a closed propellant utilization valve; actual chamber pressure after throttling was 205 psia, 16-percent rated thrust. Engine operation appeared very satisfactory at this low thrust level. The S-IVB stage propellant recirculation system was utilized successfully to prefire condition propellants at the pump inlets.

Firing J4-100-20E

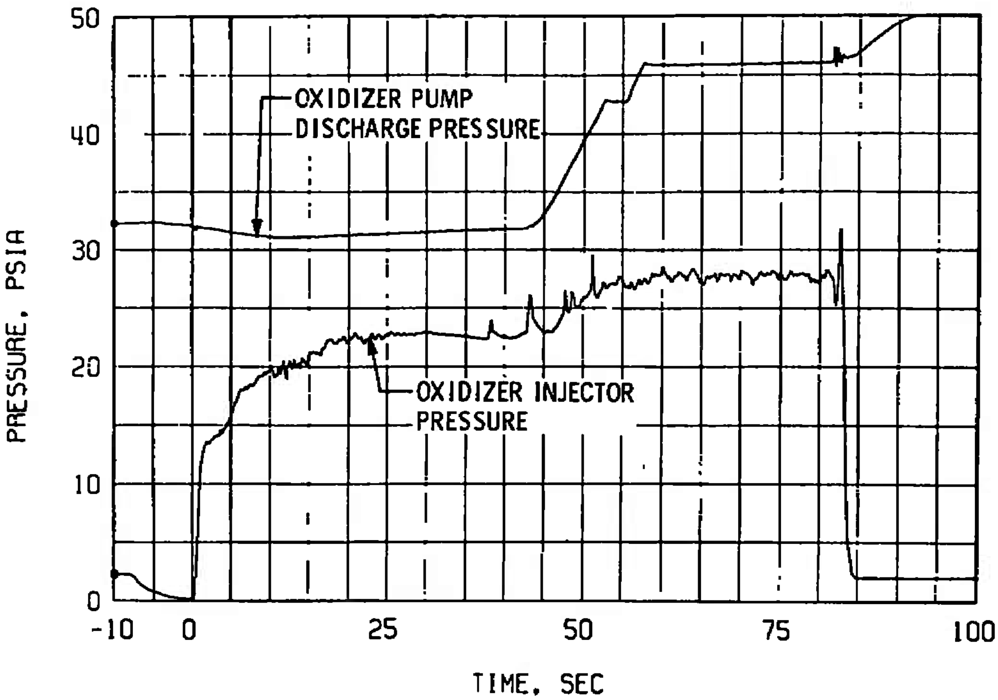
Firing 20E was a 102.2-sec idle-mode firing. The objective was to evaluate engine and pump performance at reduced fuel and oxidizer pump inlet pressures. The test was in support of Interim 21 Program, proposed use of the Saturn V, S-II Stage as a space station.



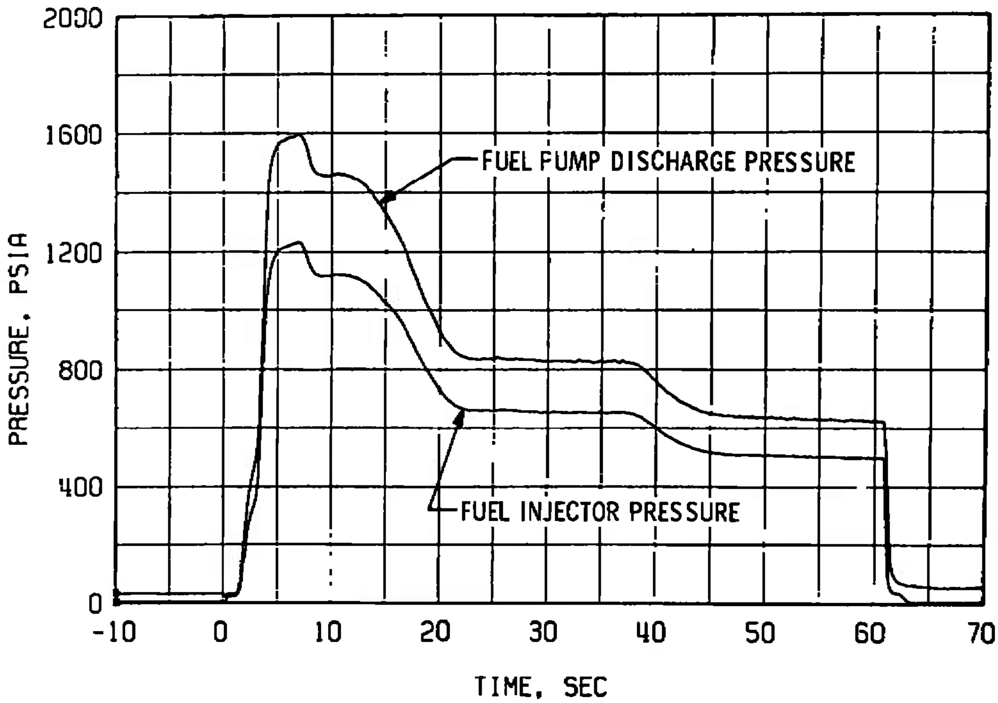
a. Engine Combustion Chamber and Test Cell Pressure, Firing 16A



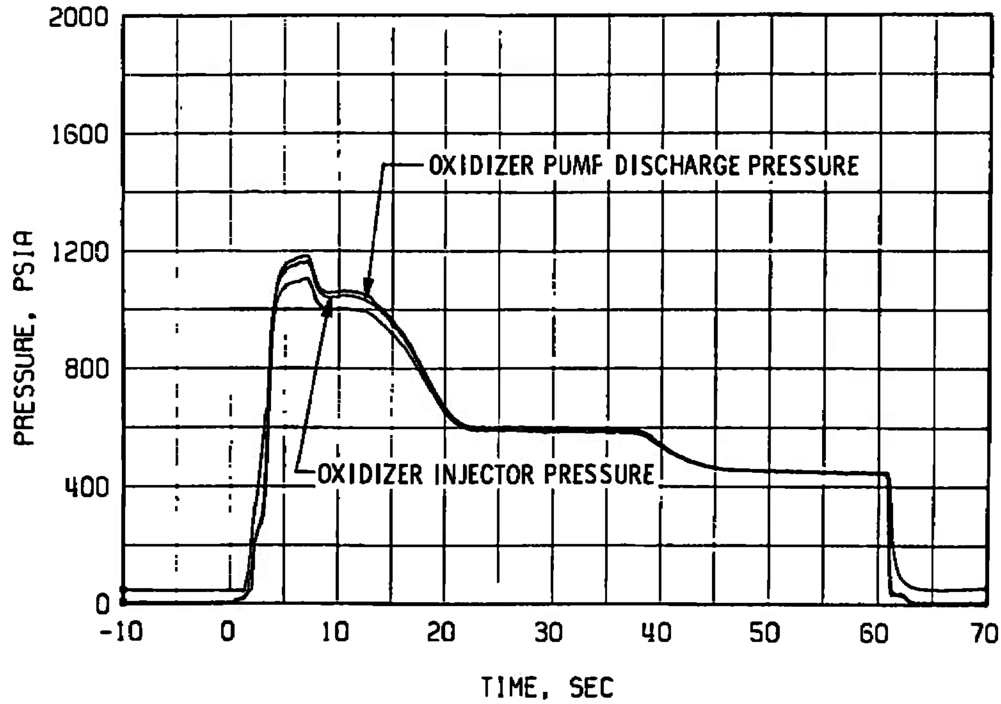
b. Fuel Pump Discharge and Fuel Injector Pressure, Firing 16A
Fig. IV-1 Pertinent Engine Parameter Performance, Test Period 16



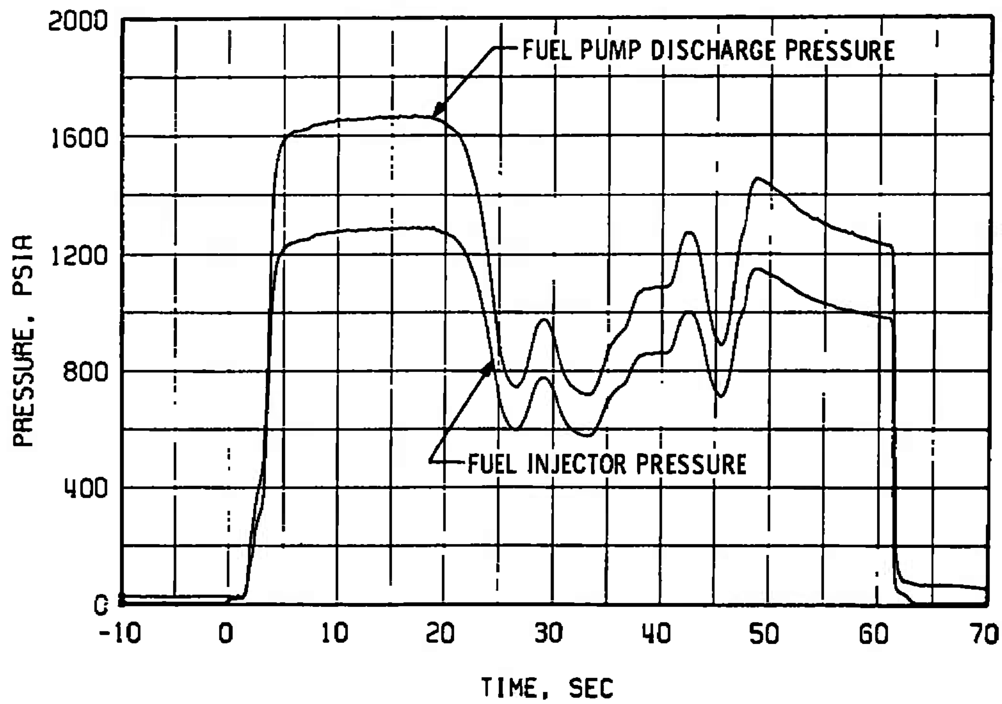
c. Oxidizer Pump Discharge and Oxidizer Injector Pressure, Firing 16A
Fig. IV-1 Concluded



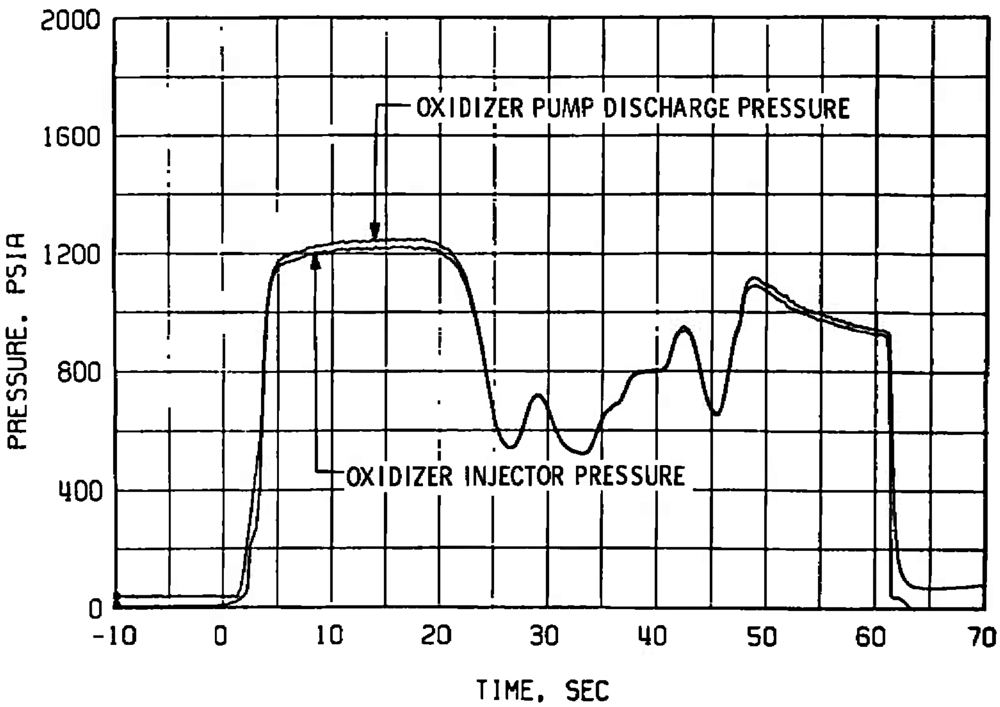
a. Fuel Pump Discharge and Fuel Injector Pressure, Firing 17A
Fig. IV-2 Pertinent Engine Parameter Performance, Test Period 17



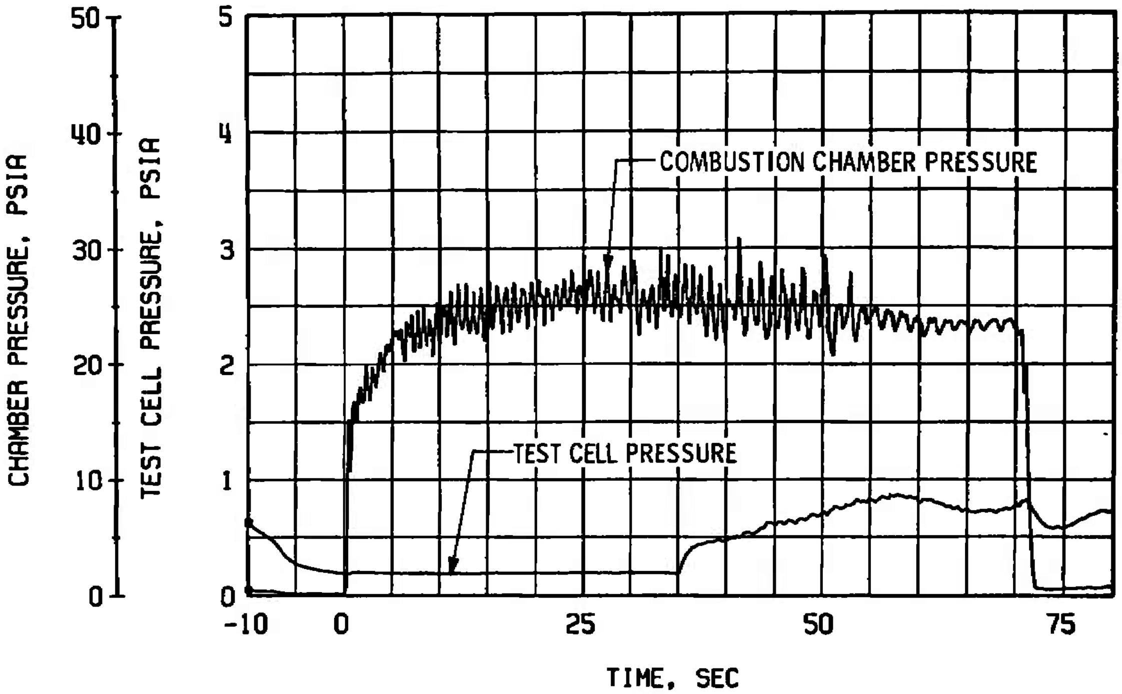
b. Oxidizer Pump Discharge and Oxidizer Injector Pressure, Firing 17A



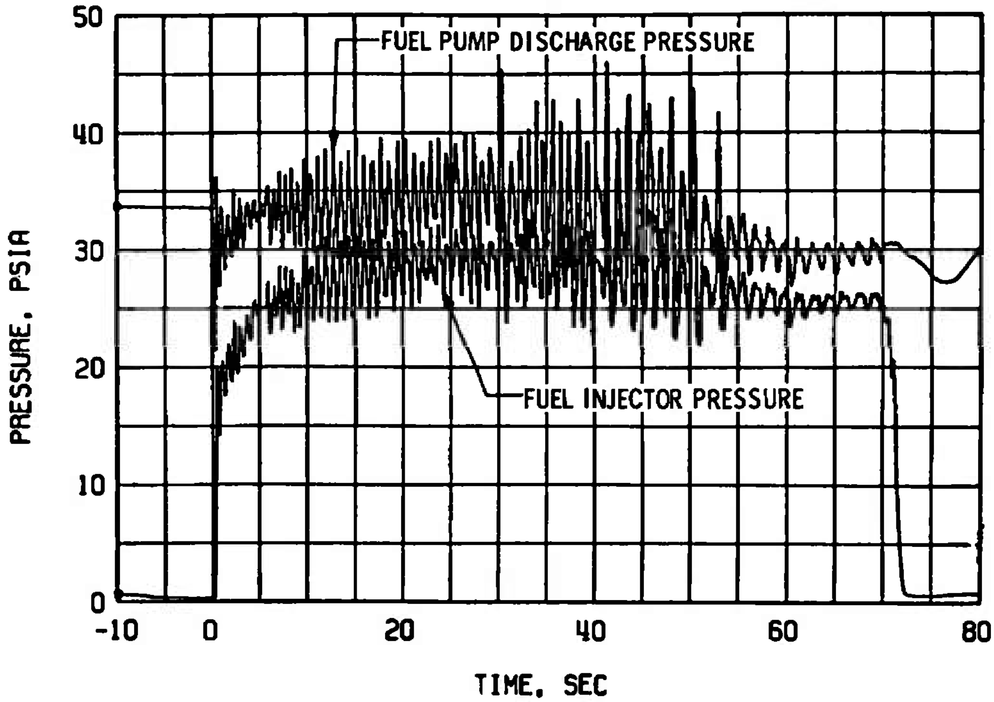
c. Fuel Pump Discharge and Fuel Injector Pressure, Firing 17B
Fig. IV-2 Continued



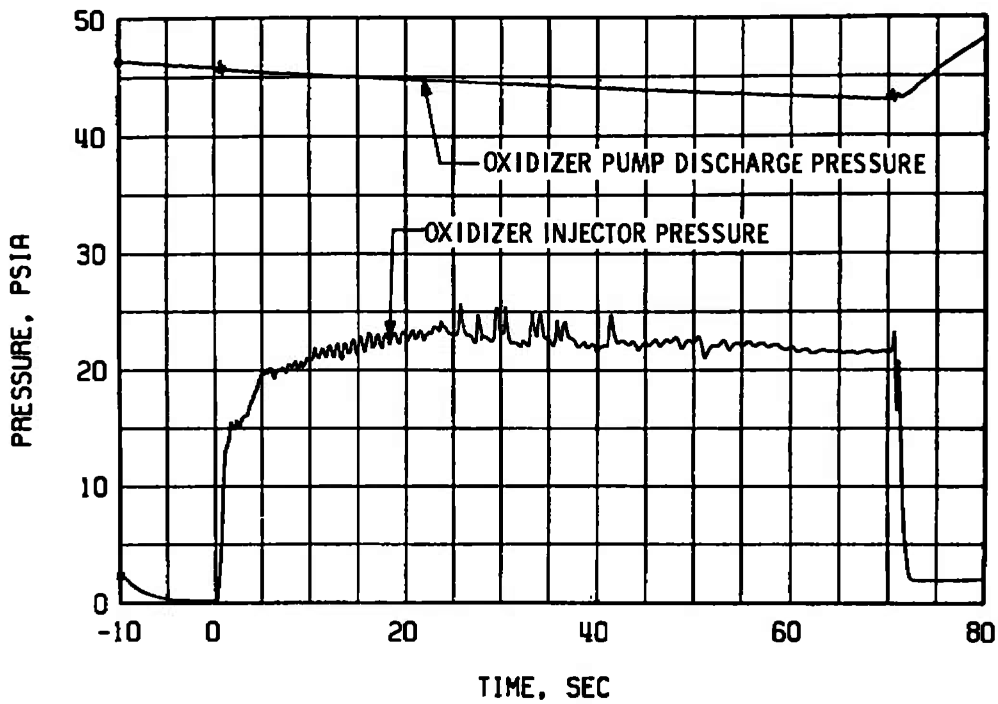
d. Oxidizer Pump Discharge and Oxidizer Injector Pressure, Firing 17B



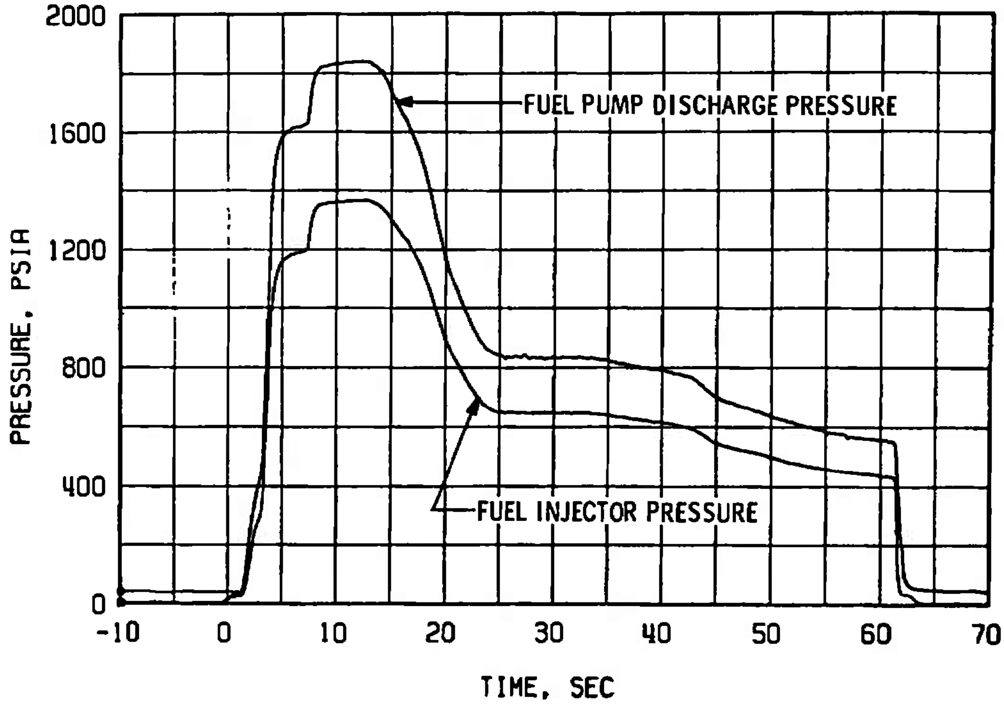
e. Engine Combustion Chamber and Test Cell Pressure, Firing 17C
Fig. IV-2 Continued



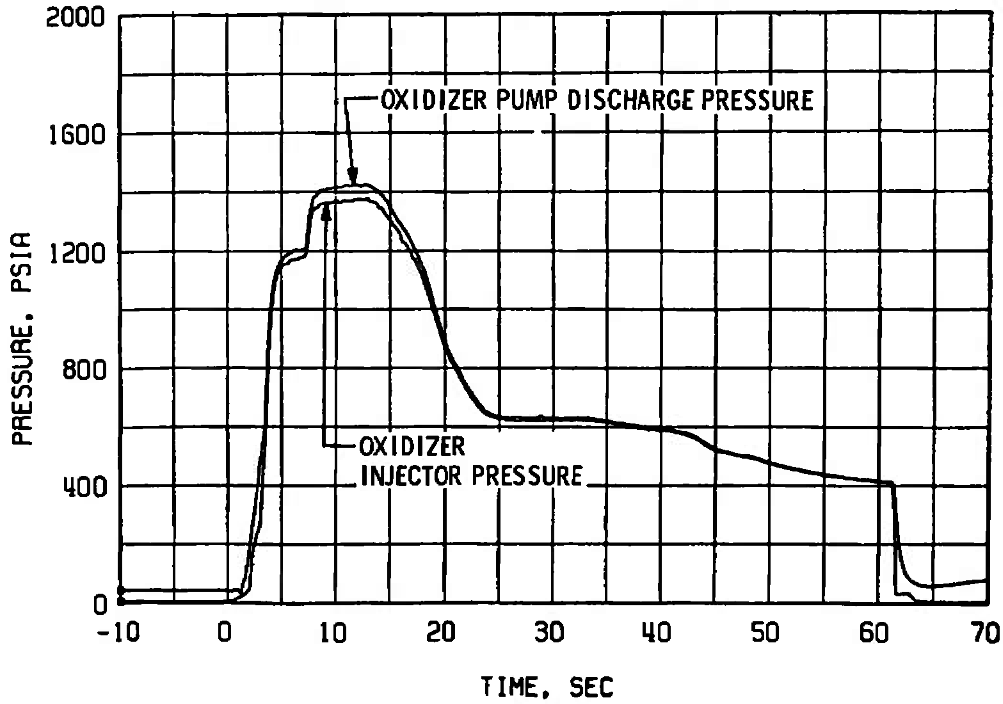
f. Fuel Pump Discharge and Fuel Injector Pressure, Firing 17C



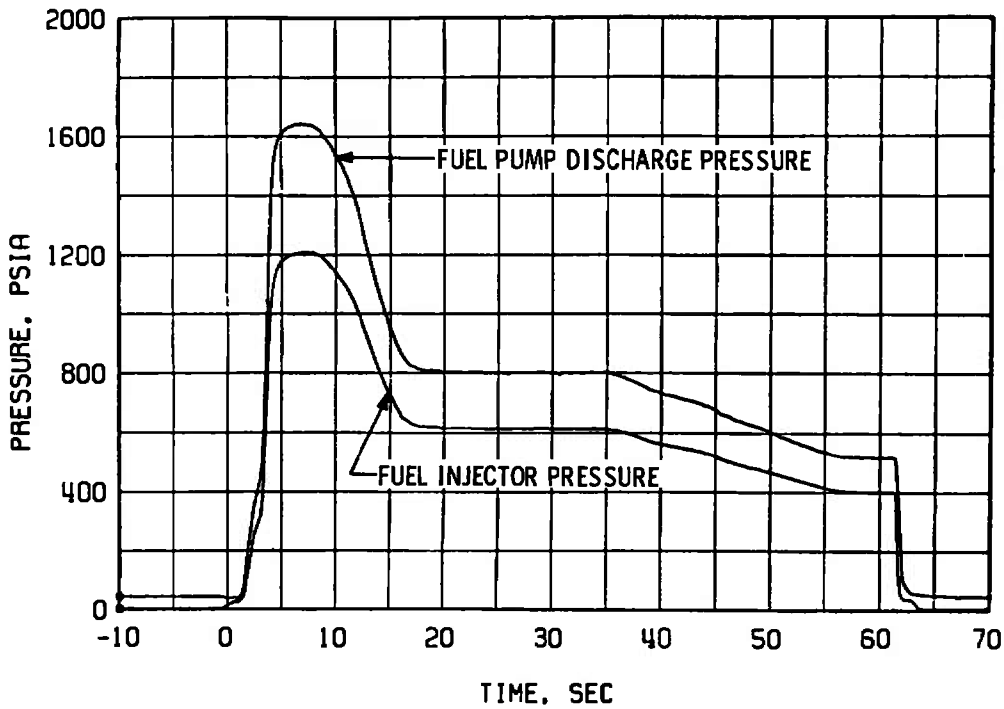
g. Oxidizer Pump Discharge and Oxidizer Injector Pressure, Firing 17C
Fig. IV-2 Concluded



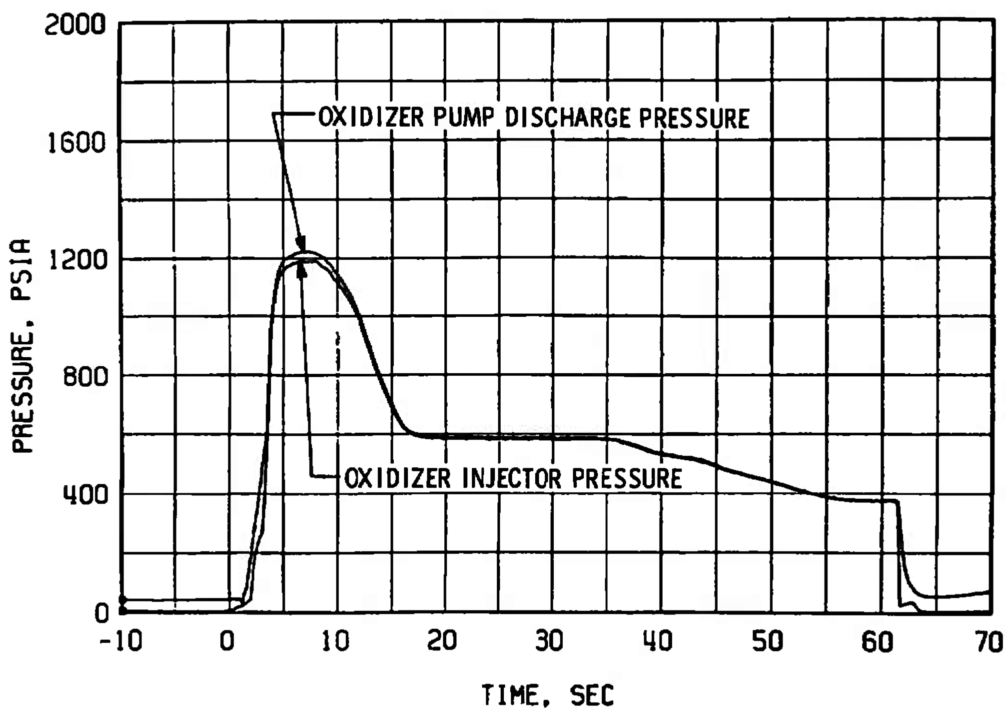
a. Fuel Pump Discharge and Fuel Injector Pressure, Firing 18A



b. Oxidizer Pump Discharge and Oxidizer Injector Pressure, Firing 18A
Fig. IV-3 Pertinent Engine Parameter Performance, Test Period 18

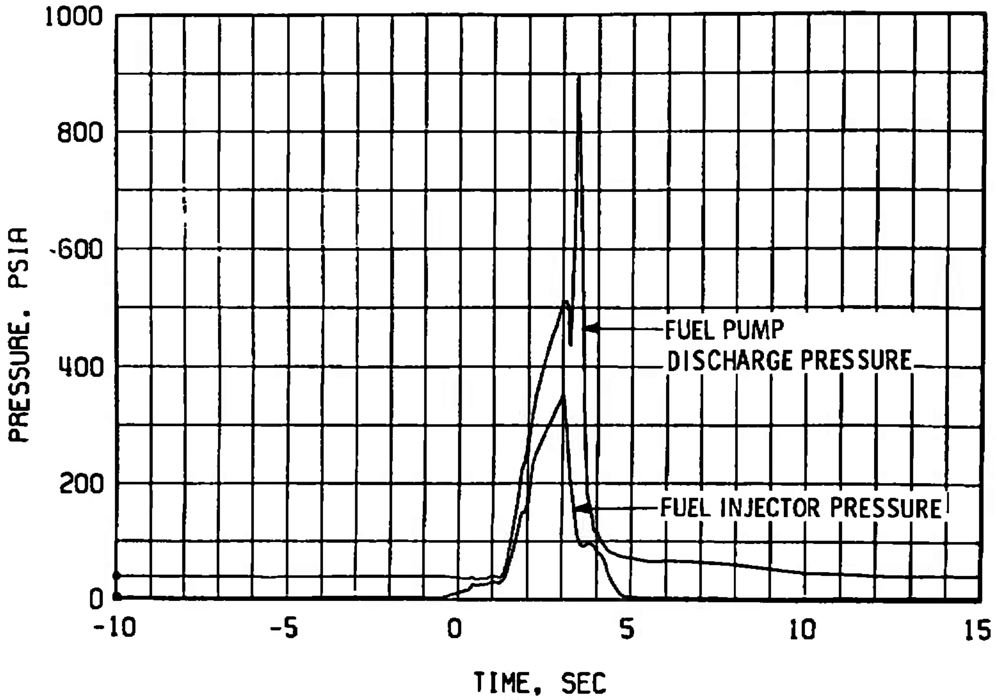


c. Fuel Pump Discharge and Fuel Injector Pressure, Firing 18B

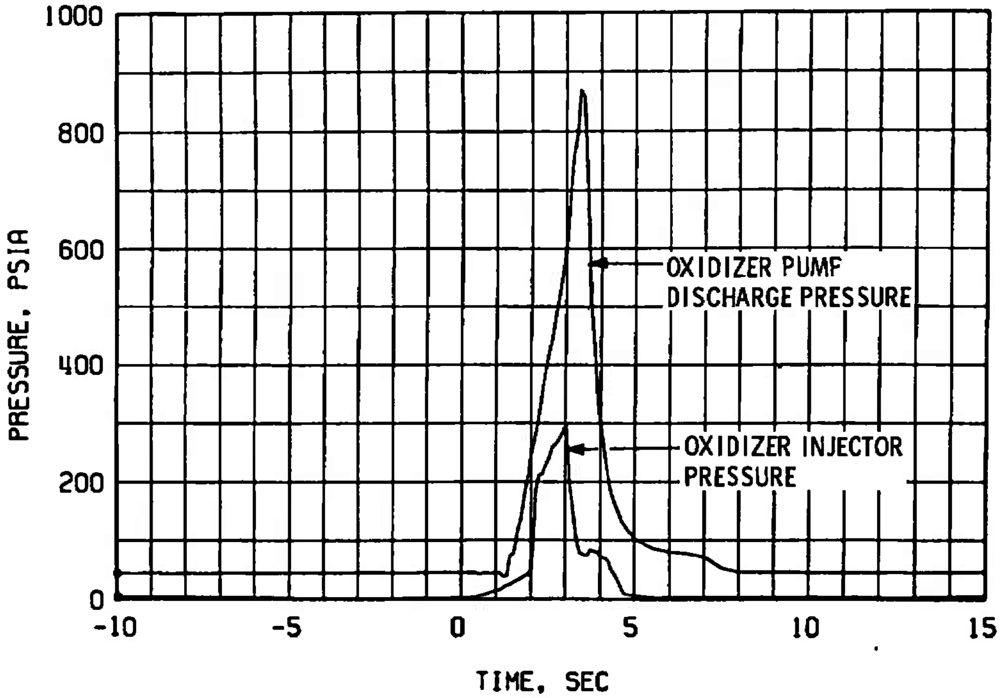


d. Oxidizer Pump Discharge and Oxidizer Injector Pressure, Firing 18B

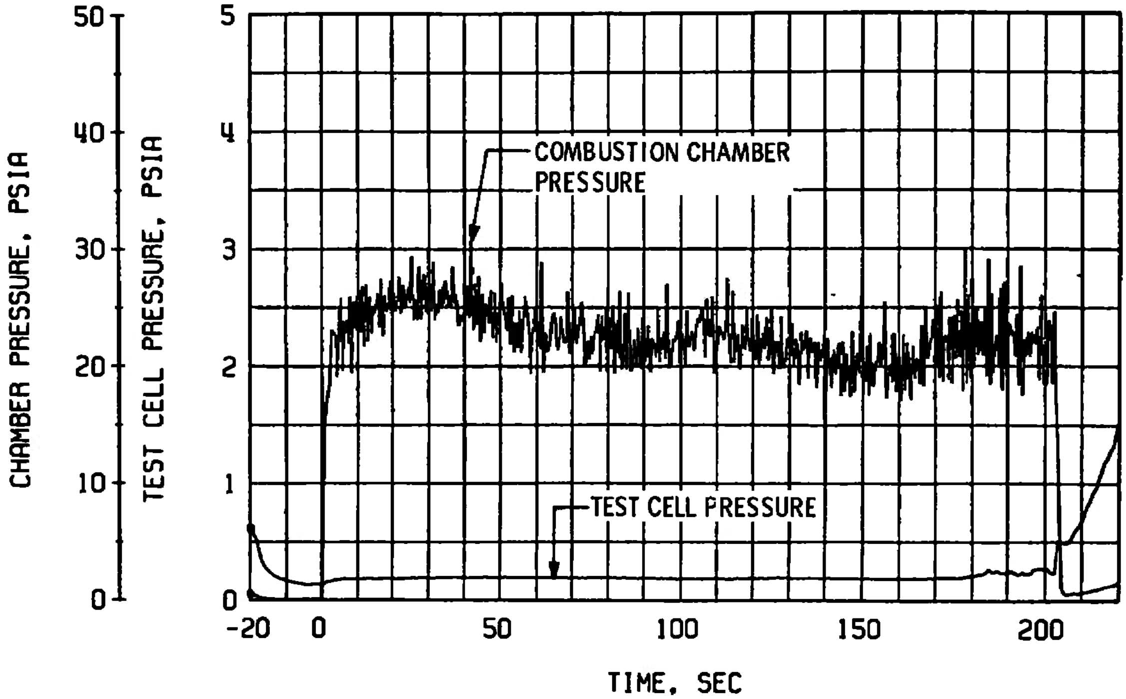
Fig. IV-3 Concluded



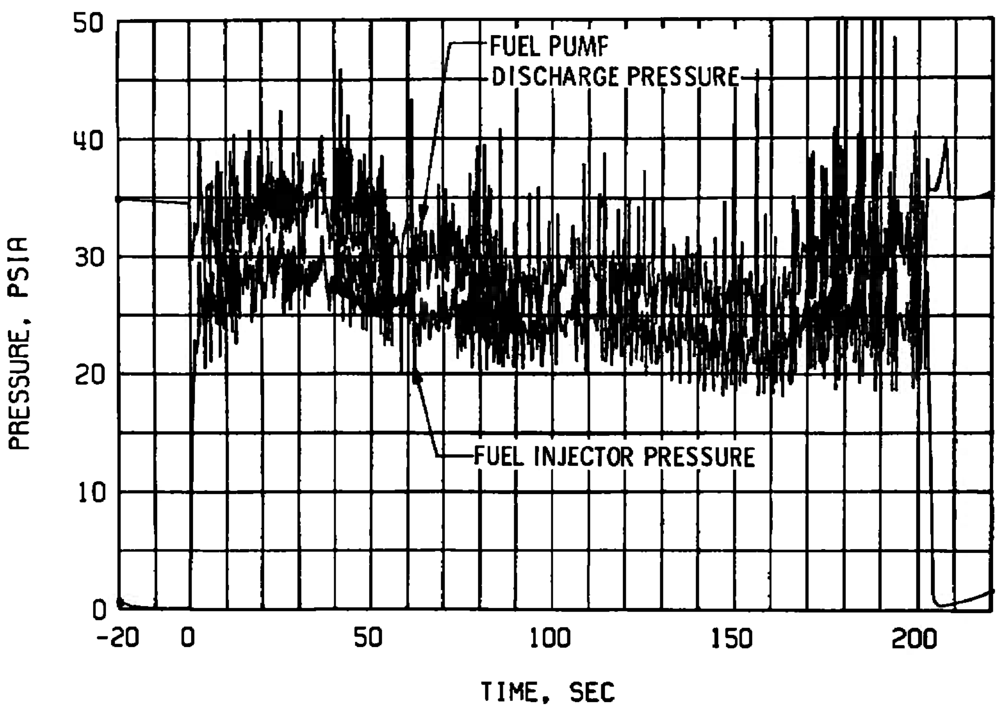
a. Fuel Pump Discharge and Fuel Injector Pressures, Firing 19A



b. Oxidizer Pump Discharge and Oxidizer Injector Pressures, Firing 19A
Fig. IV-4 Pertinent Engine Parameter Performance, Test Period 19

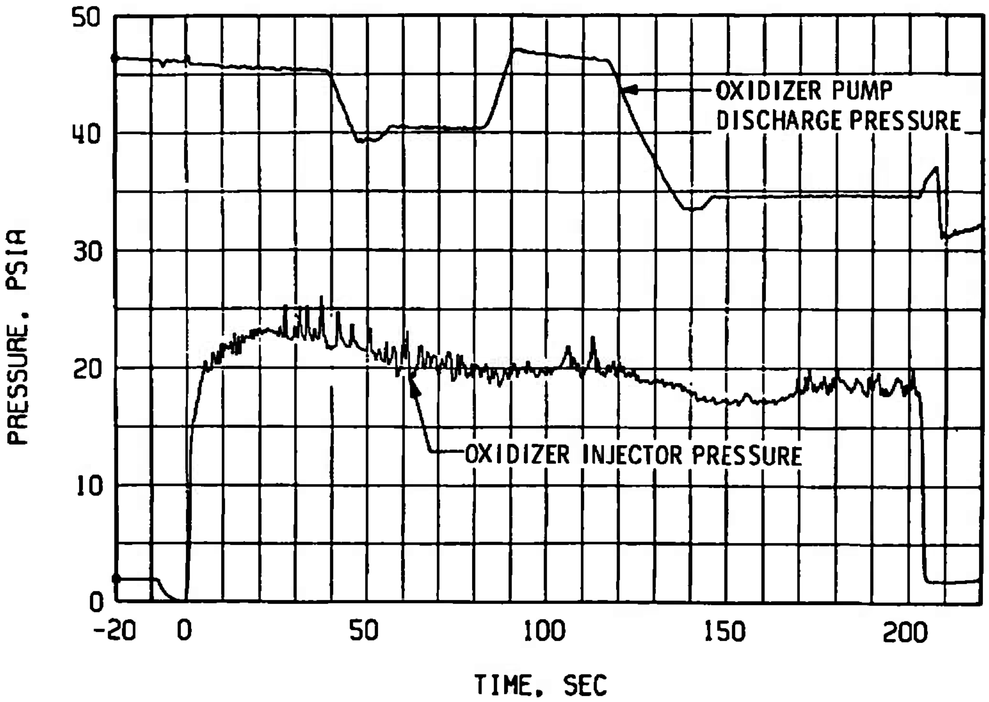


c. **Engine Combustion Chamber and Test Cell Pressure, Firing 19B**

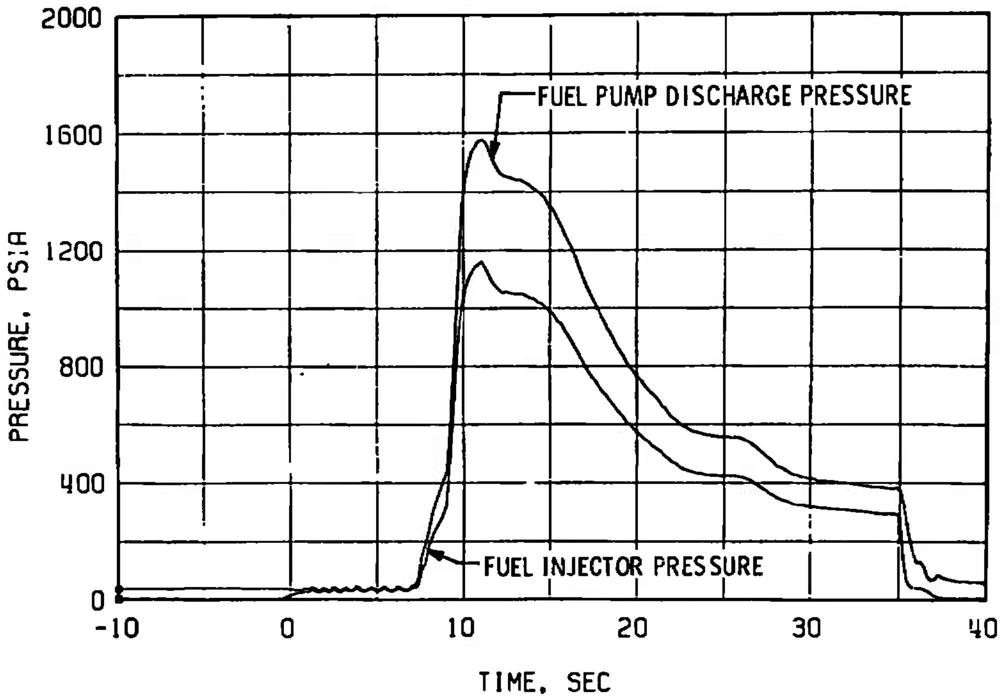


d. **Fuel Pump Discharge and Fuel Injector Pressures, Firing 19B**

Fig. IV-4 Continued

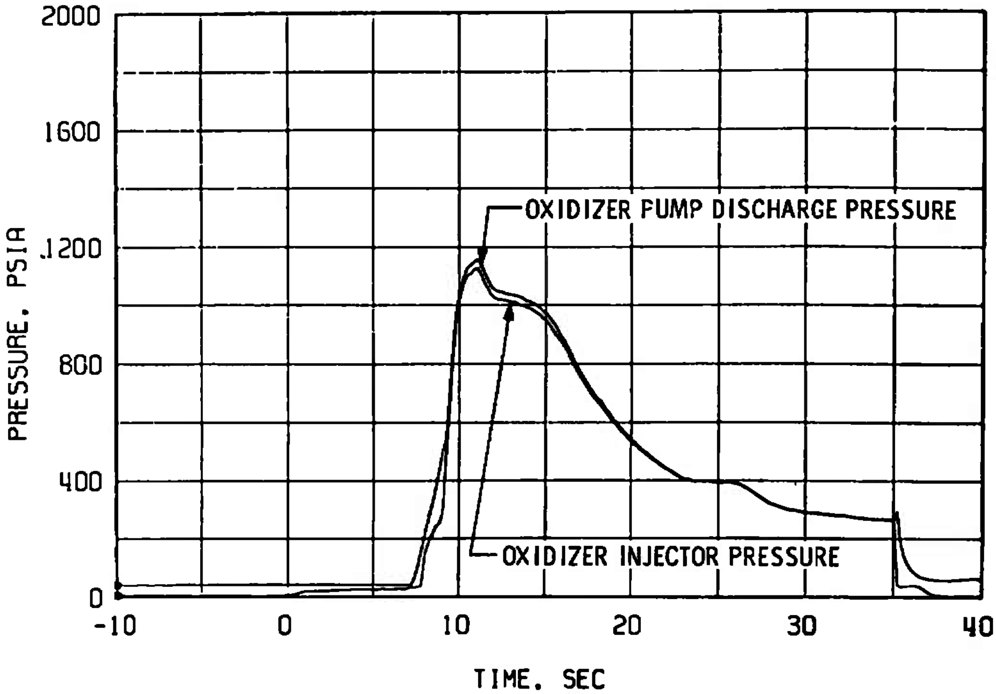


e. Oxidizer Pump Discharge and Oxidizer Injector Pressures, Firing 19B

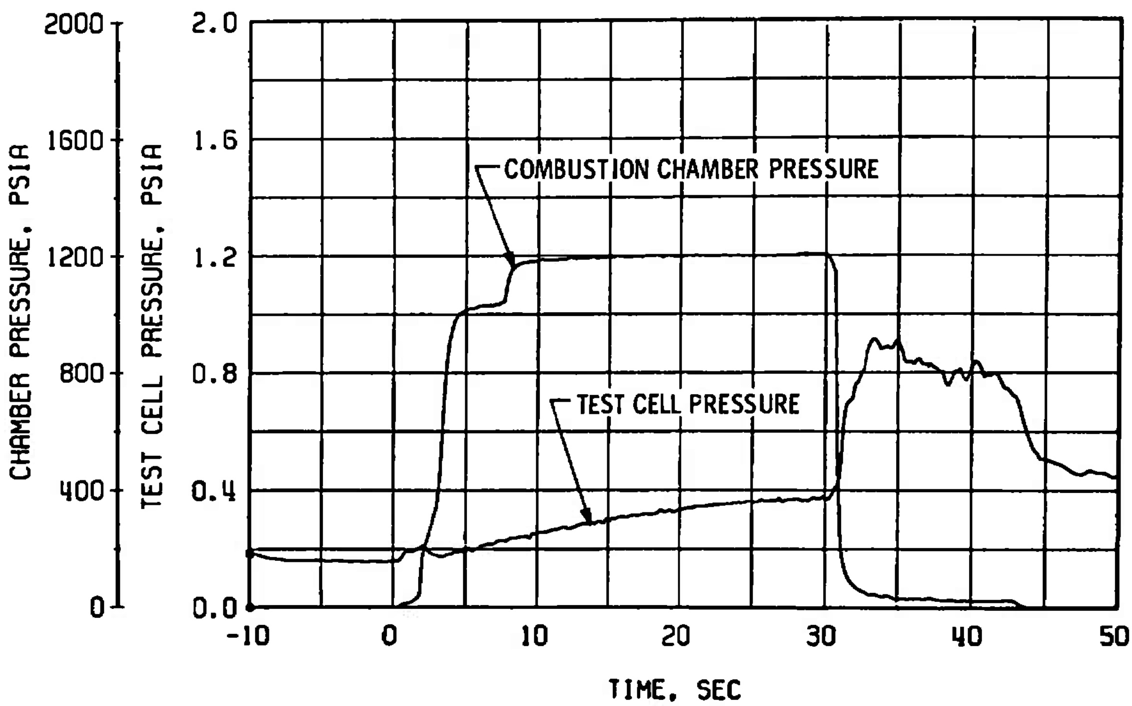


f. Fuel Pump Discharge and Fuel Injector Pressure, Firing 19C

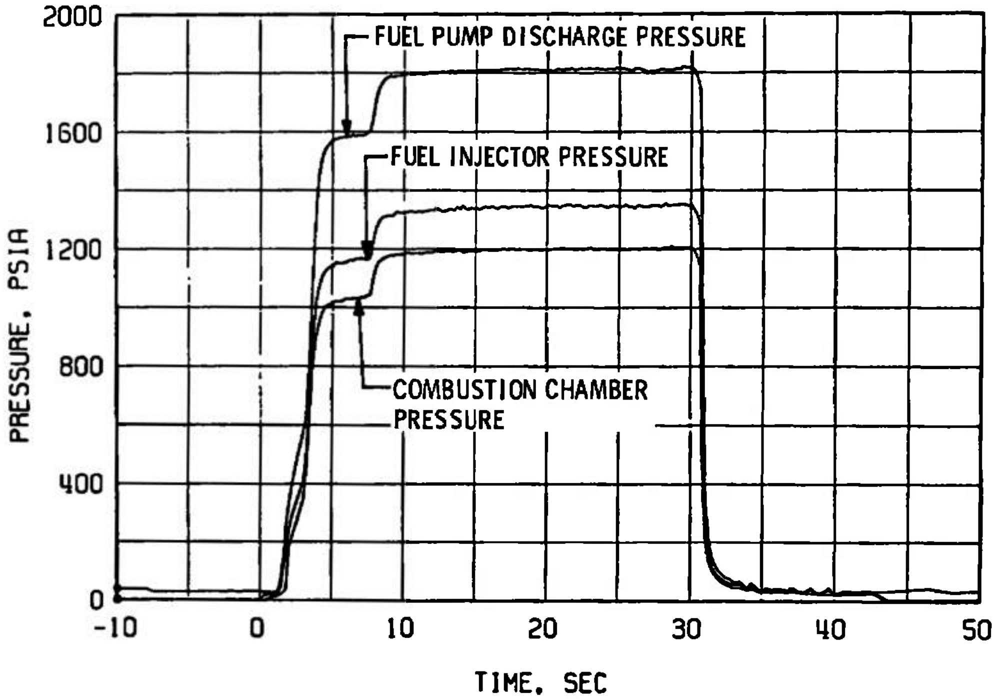
Fig. IV-4 Continued



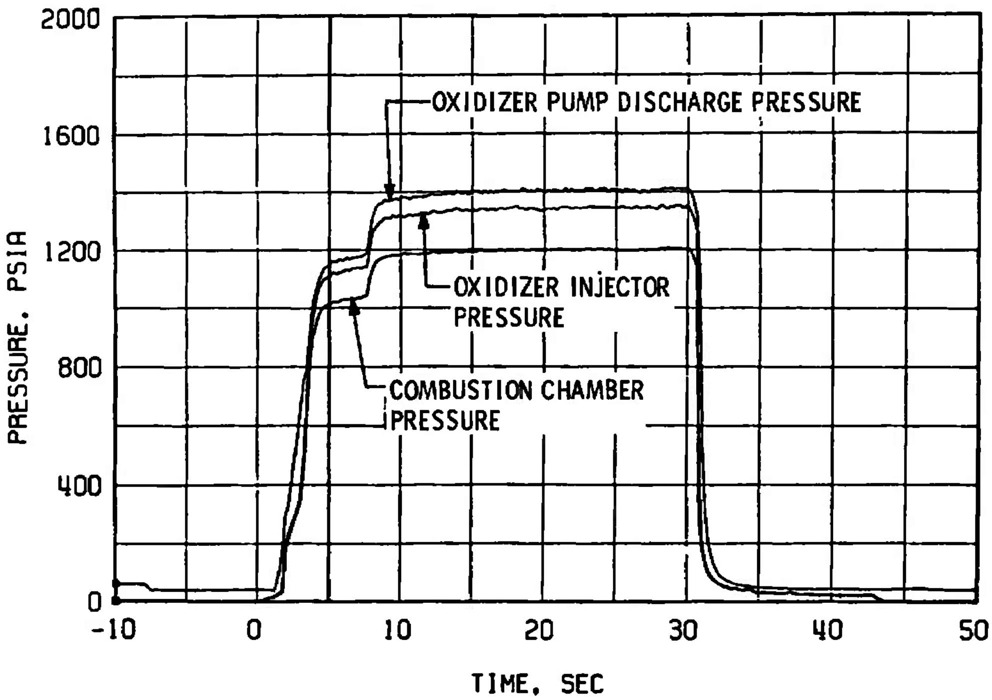
g. Oxidizer Pump Discharge and Oxidizer Injector Pressure, Firing 19C
Fig. IV-4 Concluded



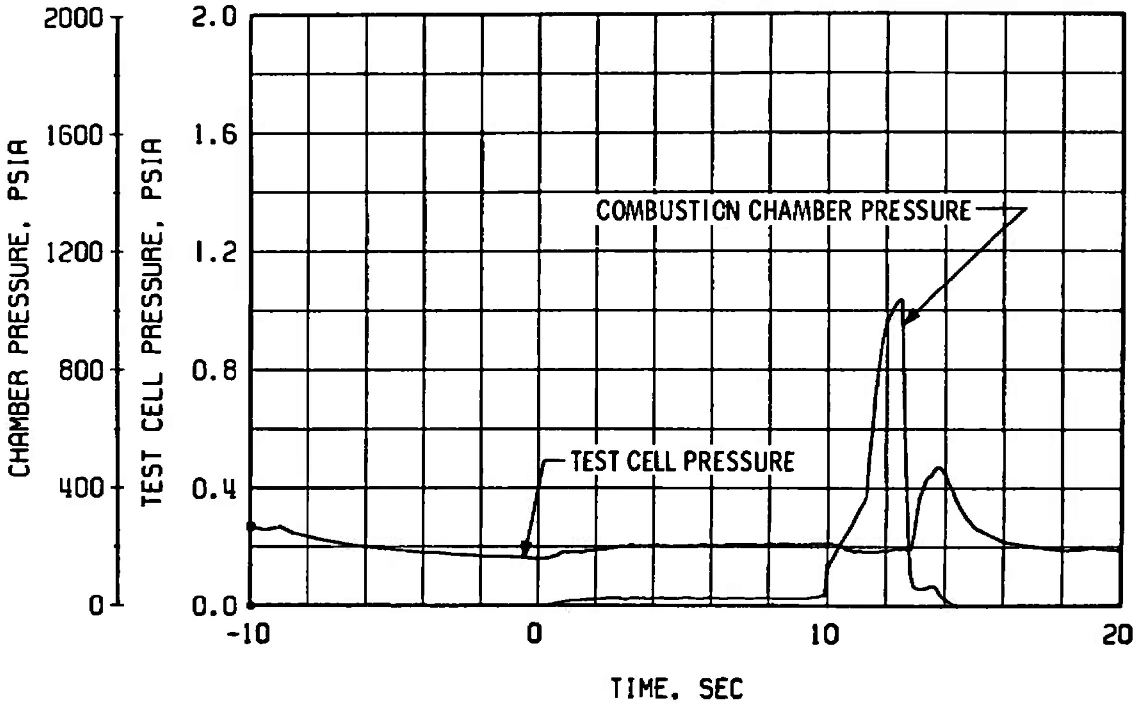
a. Engine Combustion Chamber and Test Cell Pressure, Firing 20A
Fig. IV-5 Pertinent Engine Parameter Performance, Test Period 20



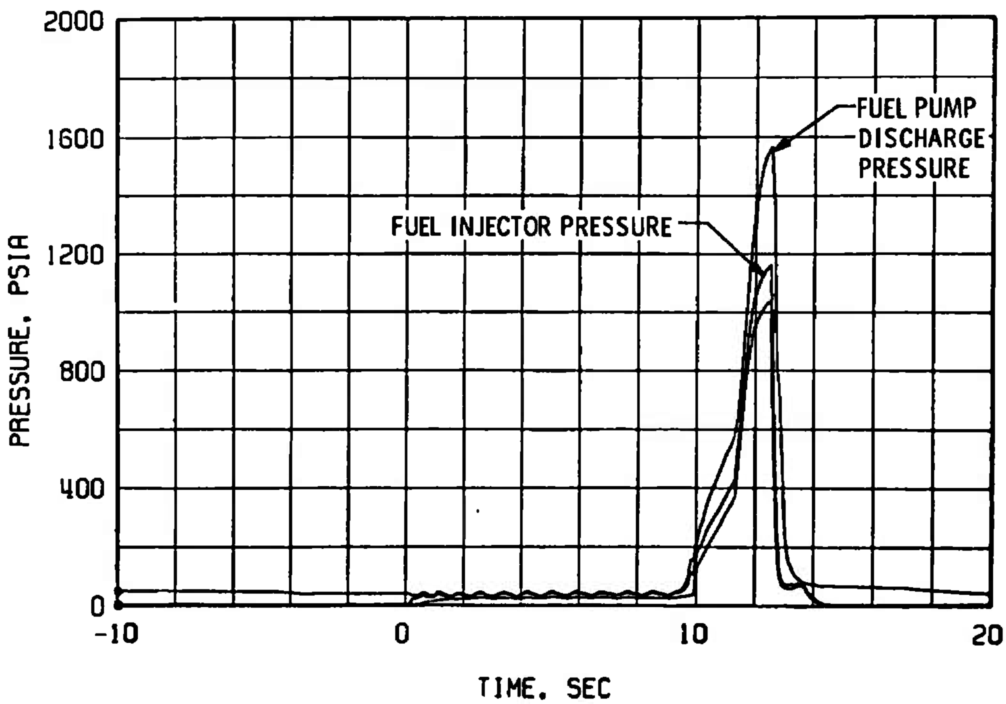
b. Fuel Pump Discharge and Fuel Injector Pressure, Firing 20A



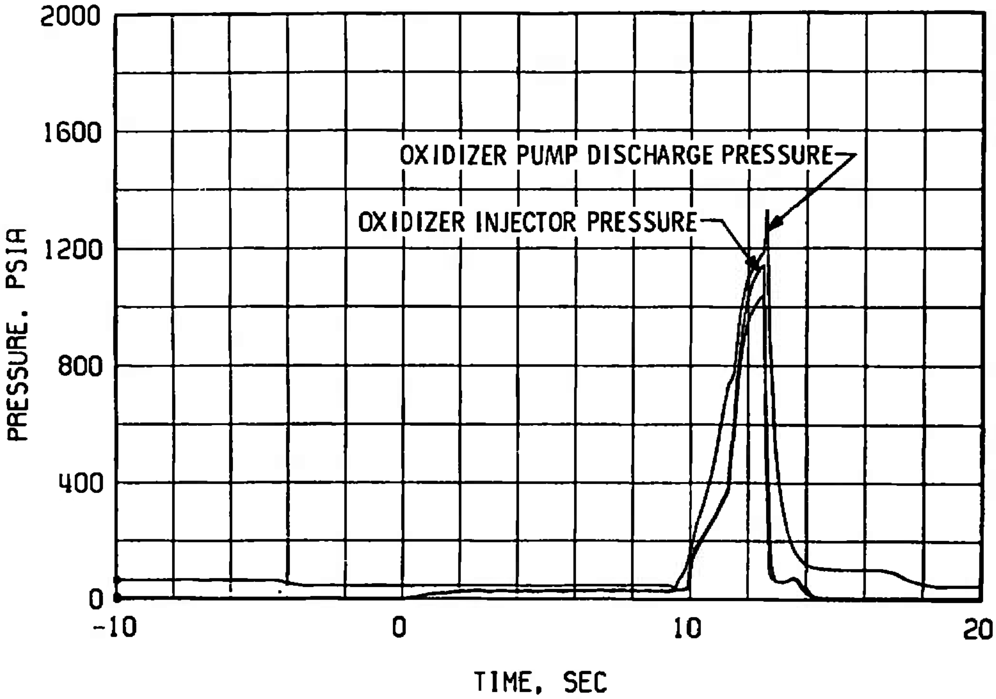
c. Oxidizer Pump Discharge and Oxidizer Injector Pressure, Firing 20A
Fig. IV-5 Continued



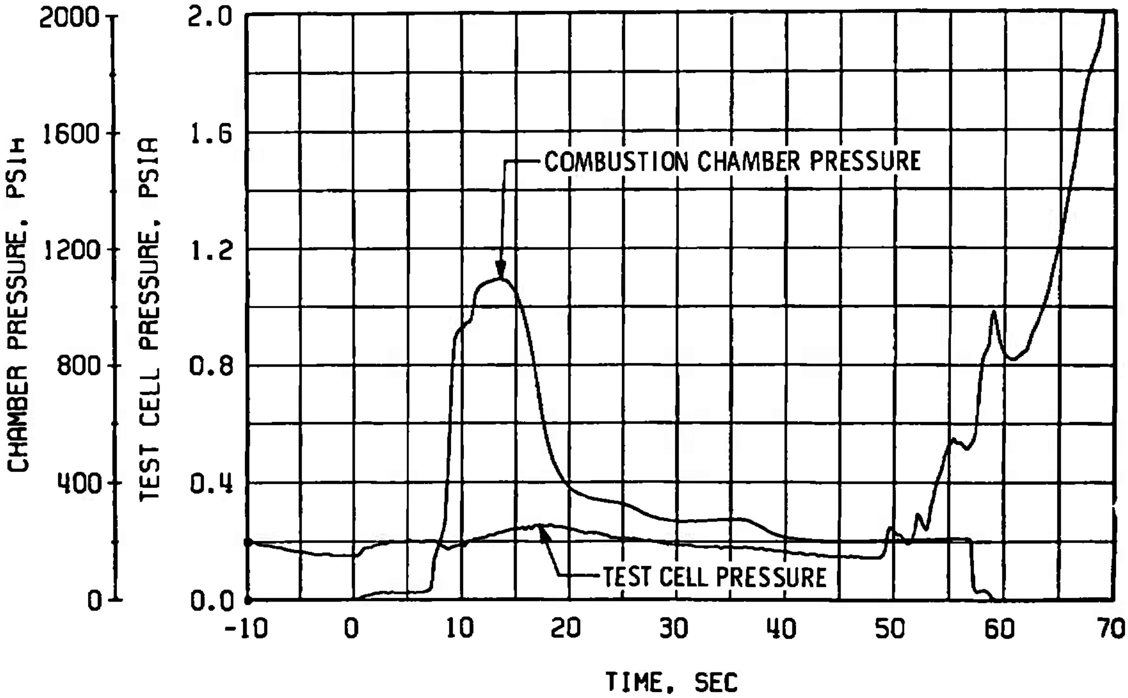
d. Engine Combustion Chamber and Test Cell Pressure, Firing 20C



e. Fuel Pump Discharge and Fuel Injector Pressure, Firing 20C
Fig. IV-5 Continued

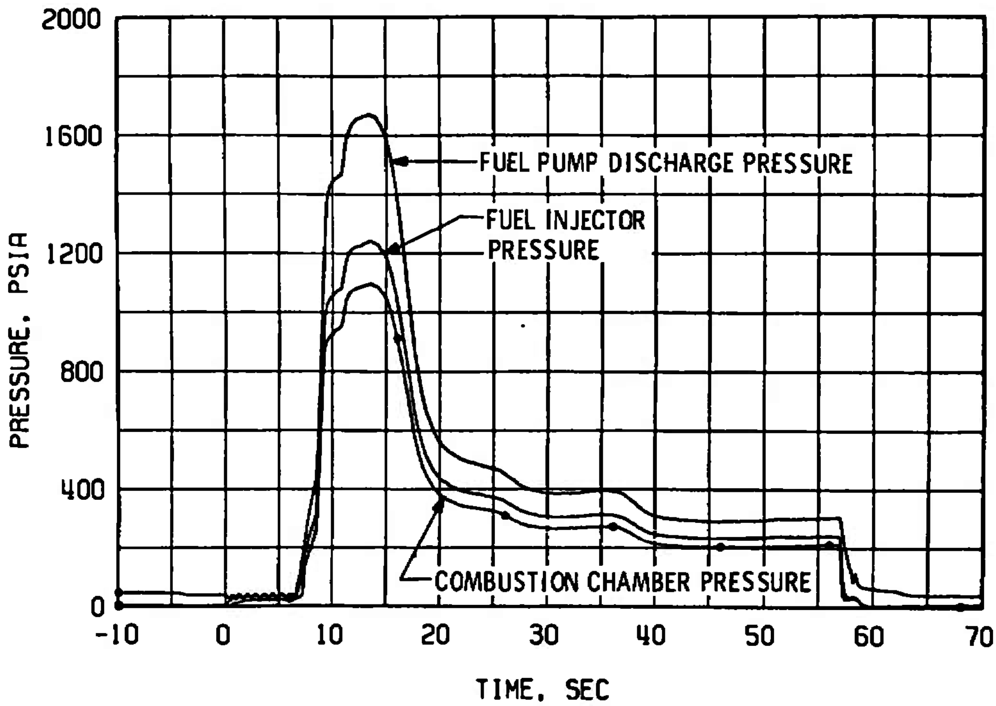


f. Oxidizer Pump Discharge and Oxidizer Injector Pressure, Firing 20C

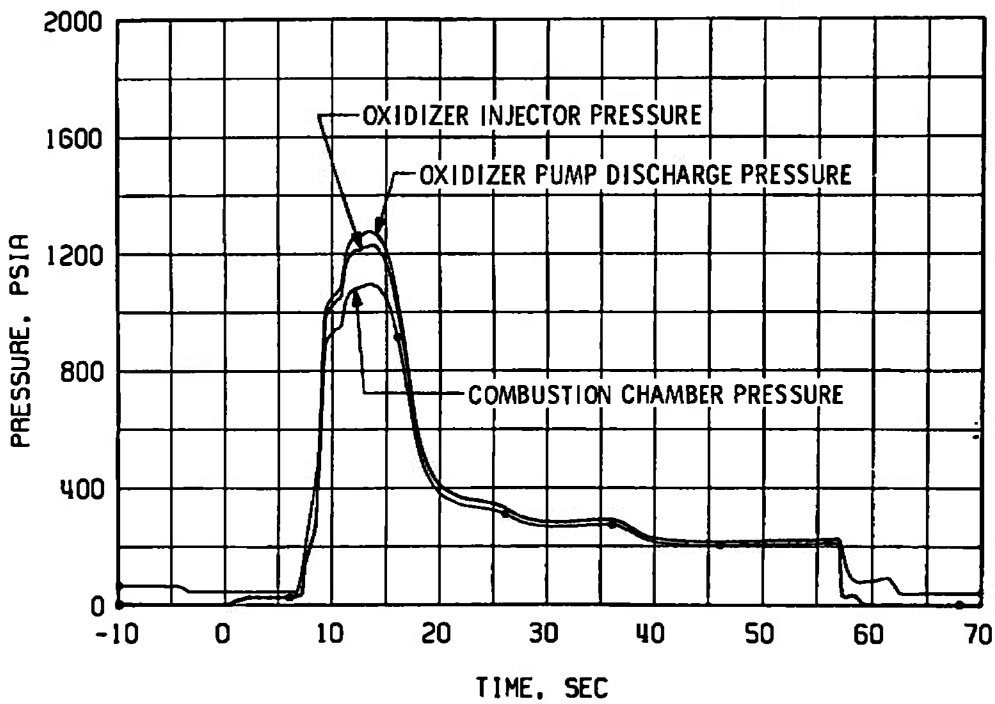


g. Engine Combustion Chamber and Test Cell Pressure, Firing 20D

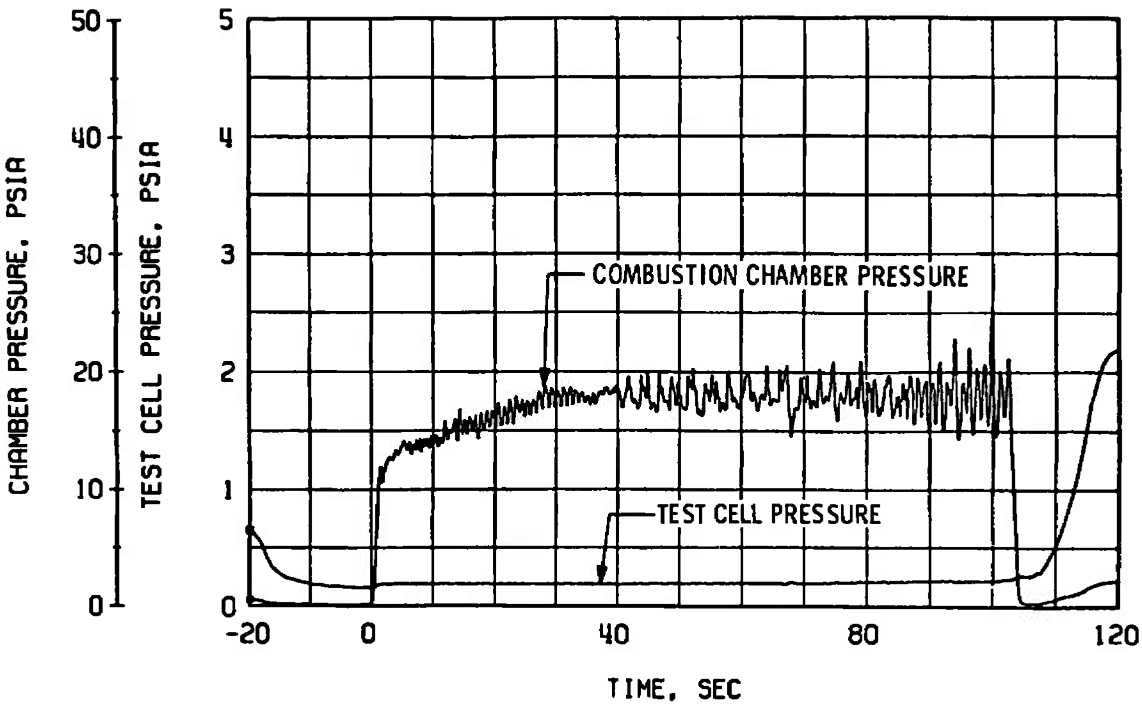
Fig. IV-5 Continued



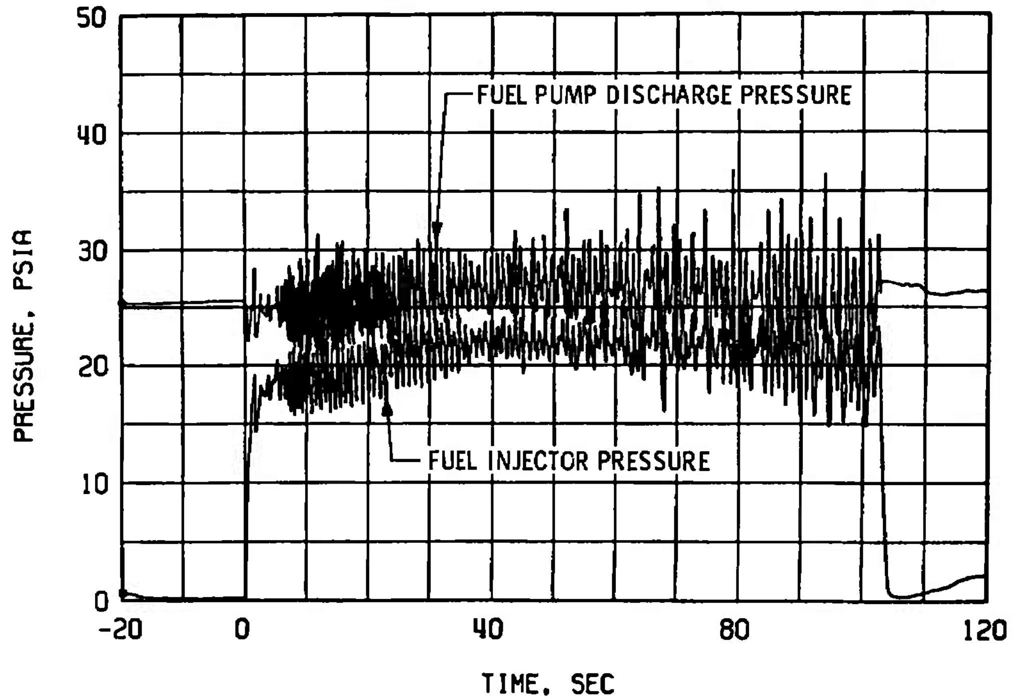
h. Fuel Pump Discharge and Fuel Injector Pressure, Firing 20D



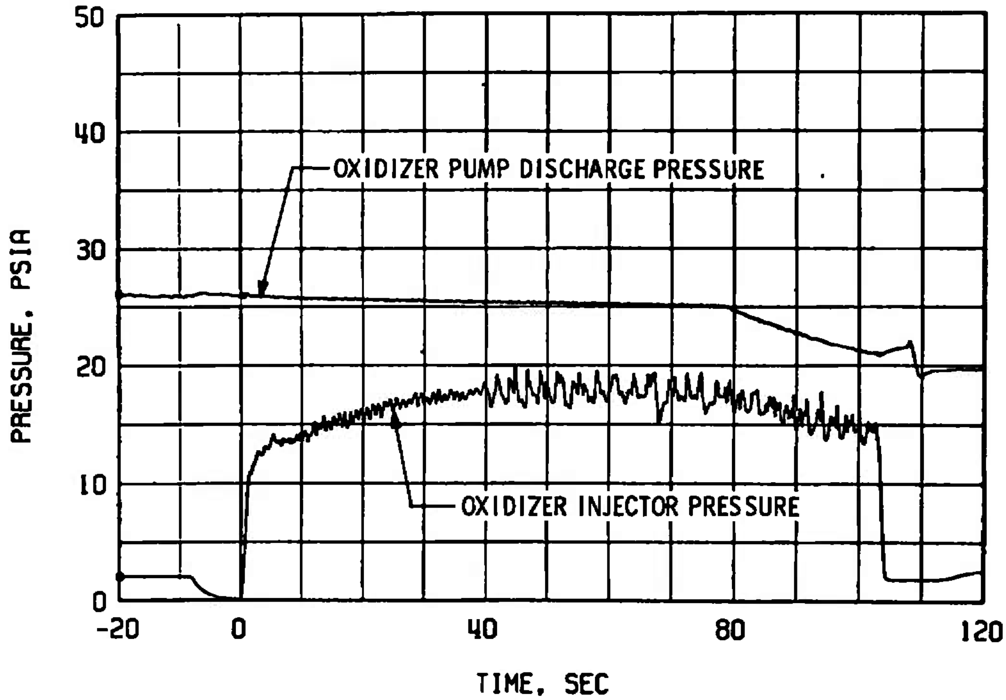
i. Oxidizer Pump Discharge and Oxidizer Injector Pressure, Firing 20D
Fig. IV-5 Continued



j. Engine Combustion Chamber and Test Cell Pressure, Firing 20E



k. Fuel Pump Discharge and Fuel Injector Pressure, Firing 20E
Fig. IV-5 Continued



I. Oxidizer Pump Discharge and Oxidizer Injector Pressure, Firing 20E
Fig. IV-5 Concluded

APPENDIX V
POWER SPECTRAL DENSITY WAVE ANALYSIS

The characteristics of a time-history signal can be described as being random, periodic, or a combination of random and periodic. These characteristics can best be understood if represented by some measure of the spectral characteristics for the signal. The spectral characteristics for any signal may be displayed as an amplitude versus frequency plot, called a frequency spectrum. The frequency spectrum for a periodic signal consists of discrete amplitude components at specific frequencies having a common multiple. The frequency spectrum for a random signal is continuous with response amplitudes possible in any frequency interval but with no discrete components at any specific frequency. Therefore, the frequency spectrum for a random signal must be presented in terms of a continuous spectral density versus frequency plot.

The most meaningful spectral density function is a density function measured in terms of mean-square values per unit frequency. Such a function is called a power spectral density function. The frequency spectrum produced by plotting a power spectral density function versus frequency is called a power spectrum.

The power spectral density is mathematically defined as:

$$G_y(f) = \lim_{T \to \infty} \lim_{\Delta f \to 0} \frac{1}{(\Delta f)T} \left[\int_0^{T} y^2_{\Delta f}(f, t)\, dt \right] \tag{1}$$

where $y^2_{\Delta f}(f, t)$ is the squared instantaneous amplitude of the signal within the narrow frequency interval from f Hz to f + Δf Hz.

The electronic equipment processes necessary to produce the exact mathematical operations required for the power spectral density equation are not possible since infinitely long averaging times (T) and infinitesimally narrow frequency intervals (Δf) are physically impossible to obtain. A power spectral density function for a stationary random signal y(t) may be approximated as:

$$\hat{G}_y(f) = \frac{1}{BT} \int_0^T y_B^2(f, t)\, dt = \frac{\overline{y_B^2(f)}}{B} \tag{2}$$

where $\overline{y_B(f)}$ is the mean-square value of the signal within a narrow frequency of f Hz, and T is a finite averaging time in seconds. Equation (2) is mechanized by the wave analyzer as shown in Fig. V-1.

The approximations made in Eq. (2), although inherent in a practical measurement system, introduce a measurement uncertainty or statistical variance. This uncertainty can be predicted to a 67-percent confidence level by the formula:

$$\epsilon = \frac{1}{\sqrt{BT}} \tag{3}$$

where ϵ is the standard error,

B is the effective filter bandwidth,

T is the integration time = 4K,

and K is the RC time constant of the averaging circuit.

For the data analyzed with a 10-Hz bandwidth and an RC time constant of 1 sec, the standard error is:

$$\epsilon = \frac{1}{\sqrt{(10)\ (4)\ (1)}} = 0.158 = 15.8 \text{ percent}$$

This would produce a power spectral density plot with 67 percent of the points falling within 15.8 percent of the true value.

At this point, it is obvious that a tradeoff must be made when determining data reduction requirements. A large averaging time, T, would tend to allow a smaller error. However, the larger T is made, the longer is the time necessary to produce a single plot. Again, the larger B is made, the smaller ϵ becomes. This, however, leads to problems in frequency resolution. Also, since in the power spectral density plot one must divide by bandwidth, a large bandwidth reduces the signal peaks while increasing the width of the pulse. If care is not taken, the data could be overlooked entirely.

Power spectral density analyses presented in this report were made with varying bandwidth filters. The values of these filters and the associated standard error are summarized below:

Bandwidth, Hz	Standard Error, percent	Frequency Range, Hz
5	22.4	5-500
50	7.1	500-10,000

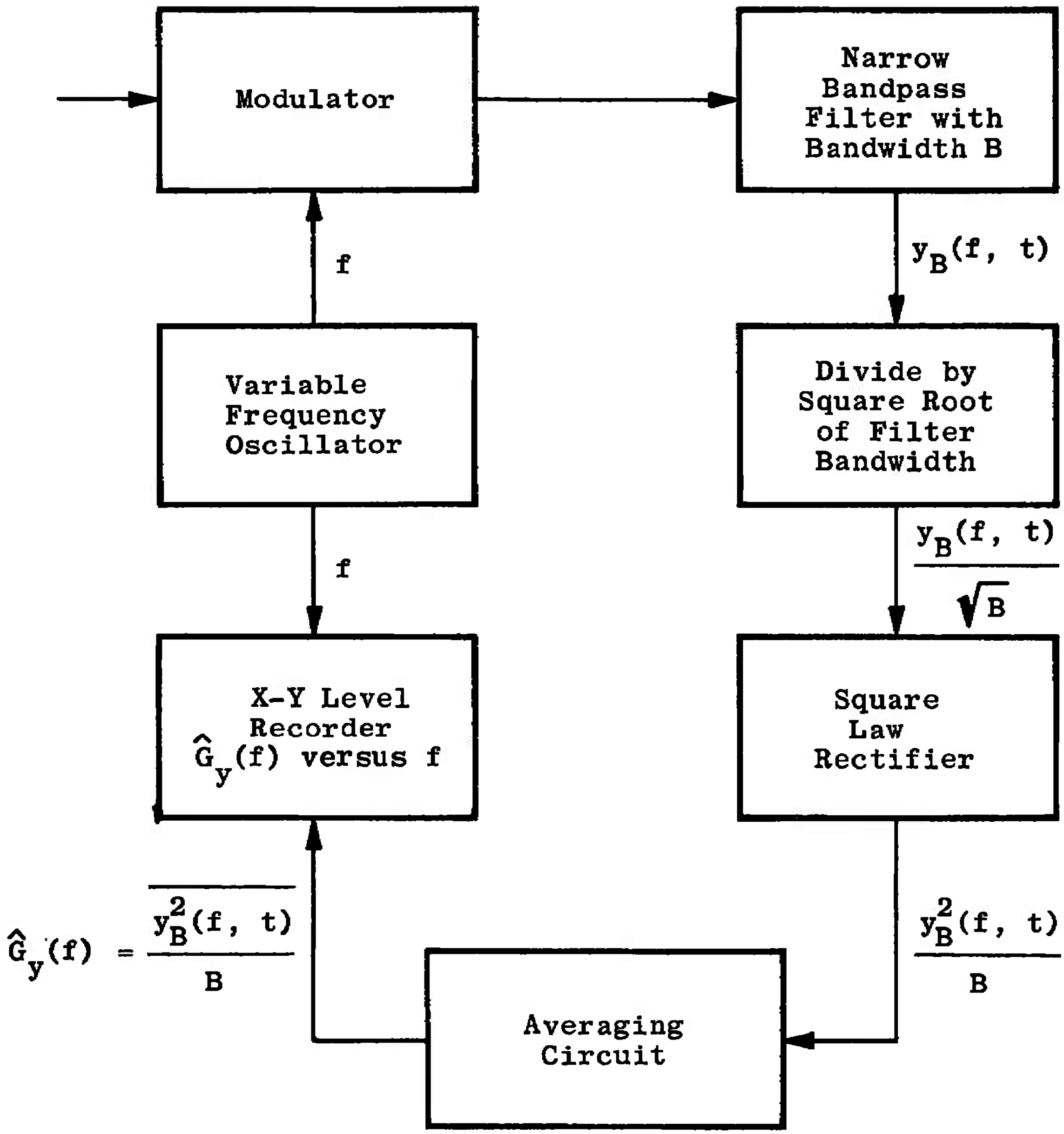


Fig. V-1 Honeywell 9300 Spectrum Analyzer, Power Spectral Density Mode

UNCLASSIFIED
Security Classification

DOCUMENT CONTROL DATA - R & D

(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)

1. ORIGINATING ACTIVITY *(Corporate author)* Arnold Engineering Development Center ARO, Inc., Operating Contractor Arnold Air Force Station, Tennessee	2a. REPORT SECURITY CLASSIFICATION UNCLASSIFIED 2b. GROUP N/A

3. REPORT TITLE
ALTITUDE DEVELOPMENTAL TESTING OF THE J-2S ROCKET ENGINE IN ROCKET DEVELOPMENT TEST CELL J-4 (TESTS J4-1001-16 THROUGH -20)

4. DESCRIPTIVE NOTES *(Type of report and inclusive dates)*
March 10 and May 19, 1970 - Final Report

5. AUTHOR(S) *(First name, middle initial, last name)*
D. E. Franklin and H. J. Counts, ARO, Inc.

6. REPORT DATE	7a. TOTAL NO. OF PAGES	7b. NO. OF REFS
November 1970	102	4

8a. CONTRACT OR GRANT NO. F40600-71-C-0002	9a. ORIGINATOR'S REPORT NUMBER(S) AEDC-TR-70-251
b. PROJECT NO. 9194	
c. Program Element 921E	9b. OTHER REPORT NO(S) *(Any other numbers that may be assigned this report)* ARO-ETF-TR-70-241
d.	

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13. ABSTRACT

Fourteen firings of the Rocketdyne J-2S rocket engine (S/N J-115) were conducted during test periods J4-1001-16 through -20 between March 10 and May 19, 1970. The major objectives of these tests were: (1) development of a throttling capability using a variable-position tapoff valve for thrust control; (2) demonstration of satisfactory idle-mode operation (both pre- and post-main stage) over a wide range of fuel and oxidizer pump inlet pressures; (3) determine the suitability of the S-IVB propellant recirculation system to prefire condition propellants and prechill engine propellant pumps; and (4) determine steady-state engine performance during main-stage operation. All major objectives were satisfactorily accomplished.

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DD FORM 1 NOV 65 1473

UNCLASSIFIED
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14. KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
J-2S rocket engine						
altitude simulation						
injector						
performance						
temperature						
fuel						
mixtures						

AFSC
Arnold AFS Tenn